Seattle Tunnel Partners
999 Third Avenue, Suite 2424
Seattle, WA 98104

WSDOT Contract No. 007999
SR 99 Bored Tunnel Alternative Design-Build Project
Phone: 206-971-8701 Fax: 206-971-8702

May 7, 2015

Serial Letter WSD-0742
S-G-GEN-TUN-TR2.52-00659-07

Washington State Department of Transportation
Alaskan Way Viaduct
999 Third Avenue, Suite 2424
Seattle, WA 98104
Attn: Matt Preedy

Re: Construction Settlement Issues (PCO #341)

Dear Mr. Preedy,

Attached a Technical Memorandum prepared by Brierley Associates, dated May 5, 2015, which addresses settlement resulting from dewatering at the TBM Access Shaft, from other construction and dewatering activities in Pioneer Square, and from ongoing regional subsidence and settlement.

This Technical Memorandum indicates that the area-wide settlement occurring in Pioneer Square is resulting from other construction and dewatering activities in Pioneer Square and from ongoing regional subsidence and settlement and therefore, not from dewatering at the TBM Access Shaft.

Please contact the undersigned if you have any questions or need more information.

Sincerely,

Chris Dixon
Project Manager

Attachment

cc: Correspondence File

Aconex: Hauser, Alonso, Magro, Stirbys, Anderson

BRIERLEY ASSOCIATES
Creating Space Underground

TECHNICAL MEMORANDUM

Date: May 5, 2015

To: Chris Dixon, Project Manager
Seattle Tunnel Partners

From: Jacob Mitchell, PE, Brierley Associates
AJ McGinn, PhD, PE, Brierley Associates
Eric Lindquist, PhD, PE, Brierley Associates
Phil Burgmeier, PE, Brierley Associates

Re: Ground Settlement from Dewatering during Construction
SR99 TBM Access Shaft
Seattle, WA

At the request of Seattle Tunnel Partners (STP), Brierley Associates (Brierley) has prepared the following technical memorandum to further investigate the apparent ground deformation in the Pioneer Square region and to evaluate other potential sources of deformation, such as construction activities and existing infrastructure. This memo serves as an extension of our January 9, 2015 memorandum on this topic.

Background

In December 2014, WSDOT's consultant, Shannon & Wilson (S&W), produced a contour map of settlement within Pioneer Square and attributed that settlement, wholly or substantially in part, to dewatering activities at the Access Shaft that began in early November. Their contours show a concentration of settlement at and just east of the Access Shaft. Despite being marked as DRAFT, these contours were shared with the City and the media. We have attached the DRAFT contours as Appendix A. We understand that this version is not the only one that has been published by S&W. The date of the baselines from which these movements have been measured is simply provided as 2010. No exact date has been provided by S&W.

At the request of STP, Brierley reviewed the magnitude of the settlement presented by S&W in Appendix A; the subsurface conditions presented in the Geotechnical Baseline Report (GBR) and at boring locations; the baselined soil stiffness parameters presented in the GBR; and observed groundwater levels at piezometer locations at the shaft and with distance from the shaft. Based on this review, Brierley concluded that the dewatering activities at the shaft could not have generated the amount of settlement reported by S&W, nor would it have resulted in the shape of the contours shown on their plot. We requested WSDOT's and S&W's calculations that formed the basis of their contour map and supported their interpretation of the data and conclusions regarding the relationship between the Access Shaft dewatering and the settlement. We received only verbal explanations and hypotheses for the settlement pattern, magnitude, and timing of the settlement that was presented on the map. Therefore, we suspect that the data was not thoroughly vetted prior to issue.

In January 2105, WSDOT and S&W revised their contour map after STP and WSDOT survey crews resurveyed the project benchmarks. Based on the revised benchmark elevations, which still had yet to be vetted thoroughly, the concentration of observed settlement migrated well away from the shaft to the southeast and slightly to the east within Pioneer Square, most notably along King Street between First Avenue and Second Avenue and near Cowgirls Bar. At the request of STP, Brierley again reviewed the data, performed calculations, and concluded that dewatering activities at the shaft could not have caused the observed levels of settlement within Pioneer Square unless the baseline subsurface conditions and stiffness parameters were materially different from those presented in the GBR. Again, we requested supporting calculations from WSDOT and S&W. To date, we have not received a response to our request to review the basis of the WSDOT and S&W contour map and the conclusions they have drawn from that map.

On January 13, 2015, we met with WSDOT, S&W, STP, and the CM team to discuss potential sources of settlement within Pioneer Square. During that meeting, STP and Brierley noted other construction projects within Pioneer Square, most notably along King Street, and the existing utilities within Pioneer Square that could be groundwater sinks that lower the groundwater table.

At the meeting, we presented contours of settlement derived from satellite data that is being provided to STP by their subcontractor, Soldata. That data is independent of terrestrial surveys that use benchmarks that require periodic adjustments. The satellite-derived data served as the basis for the contours presented in Figure 1. The contours in Figure 1 focused on Pioneer Square and were based on only the latest set of ATLAS data available at the time. Therefore, they differ some from the data presented later in this report and on subsequent figures. Figure 1 shows that settlement is concentrated away from the shaft when the area of observation is extended to the east and south. In addition, WSDOT's surveyors confirmed during our previous meeting that regional movement of their benchmarks has historically required adjustments to benchmark elevations, although the source of the movement could not be explained. At the conclusion of the meeting, WSDOT and STP discussed having an independent three member panel investigate the potential causes for the settlement and issue a report. This independent panel was never realized and STP and Brierley were later informed by WSDOT that S&W would produce a report on the observed settlement within Pioneer Square and that the report would take into consideration additional information gathered and discussed at the meeting. STP and Brierley requested a draft copy for comment prior to its release, and WSDOT verbally agreed. The report was scheduled to be released in February. To date, STP and Brierley have not been provided with background information or a draft copy of this report.

In April 2015, STP requested that Brierley undertake a review of available construction records and subsurface data for on-going construction within Pioneer Square. We also reviewed drainage (sanitary and storm sewer) maps of Seattle Public Utility and King County infrastructure within Pioneer Square. The findings of our review are presented in this technical memorandum as is an expanded analysis of the satellite survey data.

It is well documented that Pioneer Square was built on a peninsula and that large portions of the district are founded on land reclaimed from the surrounding tidal flats and tidal marsh, as shown on Figure 10, that were in-filled with uncontrolled fill. Both the fill material and underlying recent marine and tidal marsh deposits are highly compressible and susceptible to settlement induced by dewatering and vibrations as noted by their characterization in the GBR and their classification as having "high potential for liquefaction" in the Geotechnical and Environmental Data Report. Moreover, it is well documented through direct observation of WSDOT's survey benchmarks, and the continuous adjustments made to these benchmarks, that the settlement within Pioneer Square is ongoing and that the historic settlement continues to this day, as documented by the unprecedented quantity and quality of instrumentation data that is available to all stakeholders.

In addition, we note that the Alaskan Way Viaduct has experienced substantial settlement as a result of the 2001 Nisqually earthquake and ongoing monitoring indicates that the structure has continued to subside. Central Washington University has studied the post-earthquake Viaduct subsidence using GPS instrumentation as part of an earthquake hazard monitoring program (Miller, Meerteens, and Phillips, 2009). The results of this work might shed light on the full deformation field that quantifies earthquake-related subsidence and its timing relative to the Access Shaft work. Brierley has not been able to locate published information pertaining to GPS monitoring of the Viaduct by Central Washington University, and we do not know if this research is still underway.

WSDOT and S&W continue to incorrectly attribute ground deformation throughout the Pioneer Square region, wholly or substantially, to the dewatering system currently in operation at the Access Shaft. Brierley's review of the survey information collected to date and analysis of the hydrogeologic conditions refutes their assessment and confirms that settlement due to the ongoing dewatering efforts at the Access Shaft have caused only a nominal amount of ground deformation. Other causes of the settlement exist as discussed below.

Current Access Shaft Dewatering System

The dewatering system at the Access Shaft currently consists of sixteen dewatering wells. Five of these wells (DW1, DW2, DW3, DW6, and DW7) are located within the shaft itself and extend to approximately 150 ft in depth to El -135 ft. These wells were originally designed as passive wells that would depressurize the assumed ESU 7 soil layer below the bottom of the excavation. However, a redesign of these wells as an active system was required to address the differing site condition that was encountered at the Access Shaft. Four wells (DW4, DW5, DW8, and DW9) are located directly south of the shaft and adjacent to the TBM with two of them extending approximately 150 ft in depth to El -135 ft and two extending to approximately 115 ft in depth to El -99 ft. These wells were installed to lower groundwater levels within the "bathtub" to control flowing ground conditions during TBM break-in; to act as part of the active depressurization system that was required due to the differing site condition; and, to facilitate repair of the brushes within the tail shield. Three wells (SW1, SW2, and SW3) are located outside of the shaft to the northeast and extend to approximately 150 ft in depth to El -135 ft. The SW wells were installed as part of the required redesign to control hydraulic gradients within the discovered silt layer (ESU 6) in order to mitigate failure due to piping and local heave within the limits of the excavation and under the secant piles. Four wells (DDW1, DDW2, DDW3, and DDW4A) extend to approximately 200 ft in depth to El -185 ft. These deep wells were installed as part of the required redesign to prevent global heave and to control upward gradients through the soil plug below the bottom of the shaft.

The DW wells are located in the upper aquifer and are isolated by overlying and underlying aquitards. The SW wells are located within the soil plug stratum and are isolated from both the upper and lower aquifers by a bentonite seal and an aquitard, respectively. The DDW wells are located in the lower aquifer and isolated from the upper aquifer by an aquitard. The dewatering system was designed to control groundwater inflows and to depressurize distinct, isolated aquifers while mitigating drawdown in the overlying, near-surface compressible soil units.

The operational history of the dewatering wells is that the interior shaft wells were turned on in or around October while the wells adjacent to the machine were operated intermittently during this same period. The DDW and SW wells were installed in late October. The SW wells were brought online November 4, 2014. The DDW wells, except for DDW4, were brought online on November 8, 2014. Various components of the system had been tested and used prior to this intermittently. Since November 8, 2014, the system has run continuously with only short downtimes for maintenance issues. DDW4 had performance issues and was replaced by DDW4A on November 20, 2014.

Pumping rates from the system are approximately 860 gallons per minute at this time. The DDW wells are currently pumping at approximately 710 gallons per minute or about 83% of the total pumping rate. The DW and SW wells pump a combined total of 150 gpm.

On April 23, 2015, WSDOT sent a request for change proposal asking STP to decrease the pumping rates at the Access Shaft. Our April 16, 2015 letter provided STP with operational goals for the reduced pumping rates and we anticipate that work on the system to meet these new operational goals will proceed shortly.

Timeline of Settlement in Pioneer Square

Settlement in the region is historic, well documented, and ongoing. Since the existing viaduct was built, WSDOT survey data indicates that some bents near the intersection of Alaskan Way and Yesler Way have settled up to approximately 6-in. prior to October, 2014, as presented in CH2M HILL's Independent Technical Review dated April 9, 2015. WSDOT and City of Seattle survey crews routinely check and adjust their benchmarks throughout the area. We understand that in early November 2014, STP survey detected erratic readings on their surface survey points. This led to STP survey checking their primary and secondary benchmarks through November. STP survey found that their deep benchmarks DBM1 (South of Second/King Street, north of Century Link Field), DBM2 (Second Avenue between Columbia and Marion Streets), and DBM3 (Western Avenue between Seneca and University) had moved approximately 0.70-in., 0.24-in., and 0.26-in. relative to DBM4, respectively, since 2013 when the benchmarks were last surveyed directly. DBM4, DBM5, and DBM6 all appeared to have not moved relative to each other.

Following these results being published by STP survey, we understand that WSDOT checked their own benchmarks in the region and found them to have moved similar amounts to those reported by STP. We understand that WSDOT has since republished their benchmark elevations and STP has revised their survey control based on these republished elevations. We have not been provided with STP's revised survey control point elevations at this time. However, we have been provided with WSDOT's revised elevations and note that some points have had their elevations revised by as much as 1.3-in. from their 2013 values. A portion of these revised elevations have been plotted and are attached as Figure 2. A distinct trend in increase in settlement from north to south toward CenturyLink and Safeco fields can be seen in this figure. We understand that WSDOT intends to resurvey their control points and reissue benchmark corrections, if necessary, in June 2015.

In addition to the manual survey, STP's subconsultant, Soldata, has collected inSAR satellite data since July 2012. This data is presented every other month to STP in an ATLAS report. The satellite data has shown ongoing settlement in the Pioneer Square area since data collection began in July 2012. The satellite data indicate movements relative to an initial benchmark reading and are therefore not affected by, and are independent of, WSDOT's benchmark adjustments.

Brierley has extracted ground movement information from over 200 data points in Pioneer Square and the surrounding area. Figure 3 shows the locations of these data points. Figure 4 shows measured movement over the entire 31-month time period covered by the latest ATLAS Report (July 2012 through February 9, 2015). The movement measured over the 31 month monitoring period is subdivided into three discrete periods in Figures 5, 6, and 7. Figure 5 covers July 2012 to November 5, 2014; Figure 6 addresses November 5, 2014 to December 7, 2014; and Figure 7 shows the period from December 7, 2014 to February 9, 2015.

Figure 4 shows the locations that have experienced the largest settlement since mid-2012 to be in the vicinity of King Street and 1st Avenue (0.4 to 1.3 in.); near CenturyLink (0.2 to 1.4 in.) and Safeco (0.1 to 0.9 in.) Fields; near King Street Station (0.6 to 1.2 in.); along Yesler Way (0.4 to 1.0 in.); and along the railroad corridor to the east (0.4 to 1.1 in.). Figure 5 shows movement over the month following the startup of the deep wells at the Access Shaft. As can be seen in the figure, the largest movement occurred along King Street, near CenturyLink and Safeco Fields, and in the vicinity of King Street Station. Movement in the vicinity of the Access Shaft is less than 0.35-in. with the exception of points along Jackson Street and King Street. Figure 7 shows relative movement since December and shows continuing movement in the area around CenturyLink and Safeco Fields, King Street Station, around King Street and 1st Avenue, around Jackson Street and 1st Avenue, and along Yesler Way. The movement along Yesler Way between 1st Avenue and 2nd Avenue is relatively large compared to other movements in this timeframe. Points along Washington Street appear to be heaving. Points near the Access Shaft have been relatively stable.

The satellite data are in general agreement with the WSDOT benchmark adjustments that have been provided to Brierley indicating the areas of greatest settlement are at King Street and 1st Avenue and near King Street Station. WSDOT survey data south of King Street have not been provided to us.

Estimated Dewatering Related Settlement

Brierley has previously provided estimates for dewatering related settlement in the vicinity of the Access Shaft. In general, these estimates use a Young's modulus derived from the baselined unload-reload shear modulus and the thickness of the unit shown on the GBR profile or confirmed through instrumentation installations. Table 1 provides the baselined unload-reload shear moduli and their corresponding Young's moduli.

Table 1: Moduli for each ESU

Engineering Soil Unit (ESU)	Unload-Reload Shear Modulus Range (ksi)	Baselined Unload-Reload Shear Modulus (ksi)	Young's Modulus (ksi)
ESU 1	Not Provided	Not Provided	6
ESU 2	1 to 4	Not Provided	Not Used
ESU 3	0.5 to 1.7	Not Provided	Not Used
ESU 4	50 to 500	220	616
ESU 5	20 to 500	170	459
ESU 6	30 to 70	50	140
ESU 7	10 to 350	60	174
ESU 8	50 to 500	220	616

Dewatering efforts target the soils underlying the glacial till and these soils' response to dewatering is modeled as an elastic response. This approach is justified given Seattle's geologic history and has been validated by the measured response of the ground to previous dewatering efforts in the targeted aquifers. Based on this approach, the estimated settlement is a function of three parameters: modulus, thickness, and change in groundwater level.

Our November 25, 2014 response to WSDOT comments on our dewatering submittal contained a calculation, attached herein as Appendix A, for dewatering induced settlement estimates based on the measured drawdown in the instrumentation surrounding the Access Shaft. The results of that calculation were that settlement at the Access Shaft was less than 0.25-in. using the measured drawdown, baselined moduli, and thicknesses as found during the installation of piezometers. Estimated drawdown induced settlement in the underlying deep aquifer was approximately 0.08-in. at the Access Shaft location.

Brierley was subsequently asked to revisit this analysis and to consider various thicknesses and moduli for the underlying aquifer. This analysis was completed and transmitted to STP on January 9, 2015 and is attached herein as Appendix B without its attachments. The results of the analysis were in line with those from the November 25, 2014 calculation and estimated settlement to be less than 0.25-in. in the immediate vicinity of the Access Shaft with the contribution from depressurization of the underlying aquifer being less than 0.10-in. Figure 8 was provided as part of the January 9, 2015 memorandum and shows the estimated drawdown in the underlying aquifer with radial distance from the Access Shaft as measured by piezometers and observation wells in the region. Using this data, the baselined shear modulus, and an assumed aquifer thickness of 60 ft, Figure 9 was created. Figure 9 shows dewatering induced settlement in the vicinity of the Access Shaft. As noted above, estimated settlement related to depressurization of the underlying deep aquifer is less than 0.10-in. in the immediate vicinity of the Access Shaft. The estimated settlement decreases with distance from the Access Shaft in line with the drawdown from the dewatering system. The estimated settlement from the depressurization of the underlying aquifer is roughly halved at one block away from the Access Shaft and roughly quartered at two blocks away.

Brierley was also asked to back calculate the shear modulus that would be required to arrive at the reported levels of settlement at King Street and 1st Avenue. Our analysis, presented in our January 9, 2015 memo, indicated that a shear modulus between 3 ksi and 8 ksi, or 2% to 5% of the baselined shear modulus, would be required.

Other Locations of Groundwater Withdrawal in the Region and Their Potential Impact

Various sources have reported that the Access Shaft dewatering system is predominantly responsible for the settlement observed in the Pioneer Square area. However, the ATLAS survey data indicates that the areas of most movement in the region are located over 700 ft, or two blocks, from the Access Shaft and near locations of historic movement, as seen on Figures 2 and 4, and other construction activity. Based on the "bullseyes" of settlement being located well away from the Access Shaft and the calculations discussed previously, we assert that the Access Shaft dewatering system is not the predominant source of settlement observed in the region and that other causation, unrelated to the SR99 project, exists.

Our December 10, 2014 memorandum, attached herein as Appendix C with its attachments, outlined additional potential causes for the regional ground deformation. In summary, we find area seismicity, ongoing regional subsidence, and other sources of groundwater withdrawal and construction-induced vibrations to be sources of ongoing ground deformation. Since our

December 10, 2014 memorandum, other sources of groundwater withdrawal have been identified in the area, such as construction along King Street and the Enwave production well.

King Street Dewatering

There is an ongoing construction project for a residential high-rise located at 2nd Avenue and King Street. This work began in December 2014 and includes sheet piles for water cutoff and support of excavation, driven closed-ended piles, and a dewatering system consisting of well points located interior to the sheet piles.

Prior to this work, we understand that the construction of a King County sewer project took place along King Street. We have not been able to ascertain the details of this utility work, the type of dewatering system utilized, or the type of shoring system used to access the utility. However, we believe that the sewer is approximately 30 ft deep and that the ground water table is located approximately 11 ft below ground surface at this location. We are aware that the excavations for this work were dewatered. Daily dewatering discharge reports, attached as Appendix D, note that dewatering operations for the King County sewer work began on October 30, 2014 and discharged 142,500 gallons in the first day or roughly 100 gallons per minute (gpm). This flow decreased to approximately 22,000 gallons per day by November 11, 2014 and continued through at least December 12, 2014. Assuming a drawdown of 19 ft in the near surface soils and using the midpoint of the baselined stiffness range for ESU 2, we estimate that settlement due to this dewatering work would be approximately 0.75-in.

STP and Brierley are currently attempting to gather more data on the sewer work. We believe that the 6 weeks of dewatering required for this project is a major contributor to the observed deformation along King Street and in the vicinity of King Street and 2nd Avenue during the same time frame that the deep dewatering at the Access Shaft was implemented. The observed deformation in the vicinity of King Street and 2nd Avenue from November 5, 2014 to December 7, 2014 ranged from 0.25-in. to 0.53-in. as shown on Figure 6.

Enwave Seattle Production Well

Enwave Seattle has a production well that has reportedly been pumping 200 gpm out of an aquifer whose top is located at approximately EL -317 ft. We believe their pump is located at approximately EL -74 ft and we have been informed that production pumping began in late July, 2014. Static water level in this aquifer was reported as EL 18.5 ft. The aquifer that this well is located in appears to be hydraulically connected to the aquifer that the deep dewatering wells are located in at the Access Shaft.

Water level data supplied to Brierley indicates that the water level in the well during production pumping from July, 2014 to November, 2014 was approximately EL -1 ft resulting in a drawdown at the well of approximately 20 ft. In or around early November, an additional drawdown of approximately 30 ft was observed in the well.

Using the baselined shear modulus for the ESU 5 material of 170 ksi and an aquifer thickness of 60 ft, settlement of 0.01-in. would have resulted from the production pumping at the Enwave well. After the additional drawdown in November, settlement of 0.03-in. would have resulted from changes in water pressure at the Enwave well.

If a reduced shear modulus of 8 ksi is used, as was calculated as being required to match settlement at King Street and 1st Avenue to the observed drawdown levels, then a settlement of

0.28-in. should have been observed at the Enwave well location from production pumping. After the additional drawdown in November, settlement of 0.70-in. should have been observed at the Enwave well location from changes in water pressure.

We note that Figures 4 through 7 indicate that similar settlements to those predicted for the 8 ksi case appear to be reported near the Enwave well location. However, the two points that show these settlements in the Figures are representative points taken from the top of the Viaduct and that points adjacent to and on the Enwave building all show deformation that is consistent with the deformation measured at Western Avenue and Union Street.

We believe this lack of deformation at the Enwave well location further strengthens our position that the soils that make up the deep aquifer are too stiff to have resulted in the settlements reported in the Pioneer Square area.

Existing Utilities in Pioneer Square

The City of Seattle has conducted maintenance on their utilities throughout the Pioneer Square region for the duration of the SR 99 project. Many of these utilities are aging with some utilities having been in service since as early as 1890. We understand that odor control facilities and other upgrades to the City's infrastructure have been constructed in the Pioneer Square area over the SR 99 project's lifetime and that routine maintenance has been undertaken by the City on their infrastructure. When asked for maintenance records for their utilities, City representatives informed Brierley that they were not available.

Safeco Field Underdrains

Brierley recently discovered that Safeco Field contains a large, permanent underdrain system that continuously depresses the groundwater table. In addition, Safeco Field was constructed over the Elliot Bay interceptor and closed-end pipe piles were installed immediately adjacent to this interceptor. We are not aware of any pre or post-construction surveys of the sewer that would document its condition or infiltration rates into the sewer.

We understand that this permanent underdrain system is located in the fill. This continuous drawdown of the groundwater table in the vicinity of Safeco Field is a potential source of ongoing settlement in the area around Safeco Field.

Concluding Remarks

Our analyses, combined with the locations of greatest settlement and the timing of the settlement, indicate that the ground deformation in the Pioneer Square area is not largely the result of dewatering at the Access Shaft. The majority of the settlement reported in the Pioneer Square area since Access Shaft dewatering began is due to a continuation of ongoing regional subsidence and settlement due to other construction and dewatering activities in the Pioneer Square area, especially those related to maintenance and replacement of Pioneer Square's aging infrastructure.

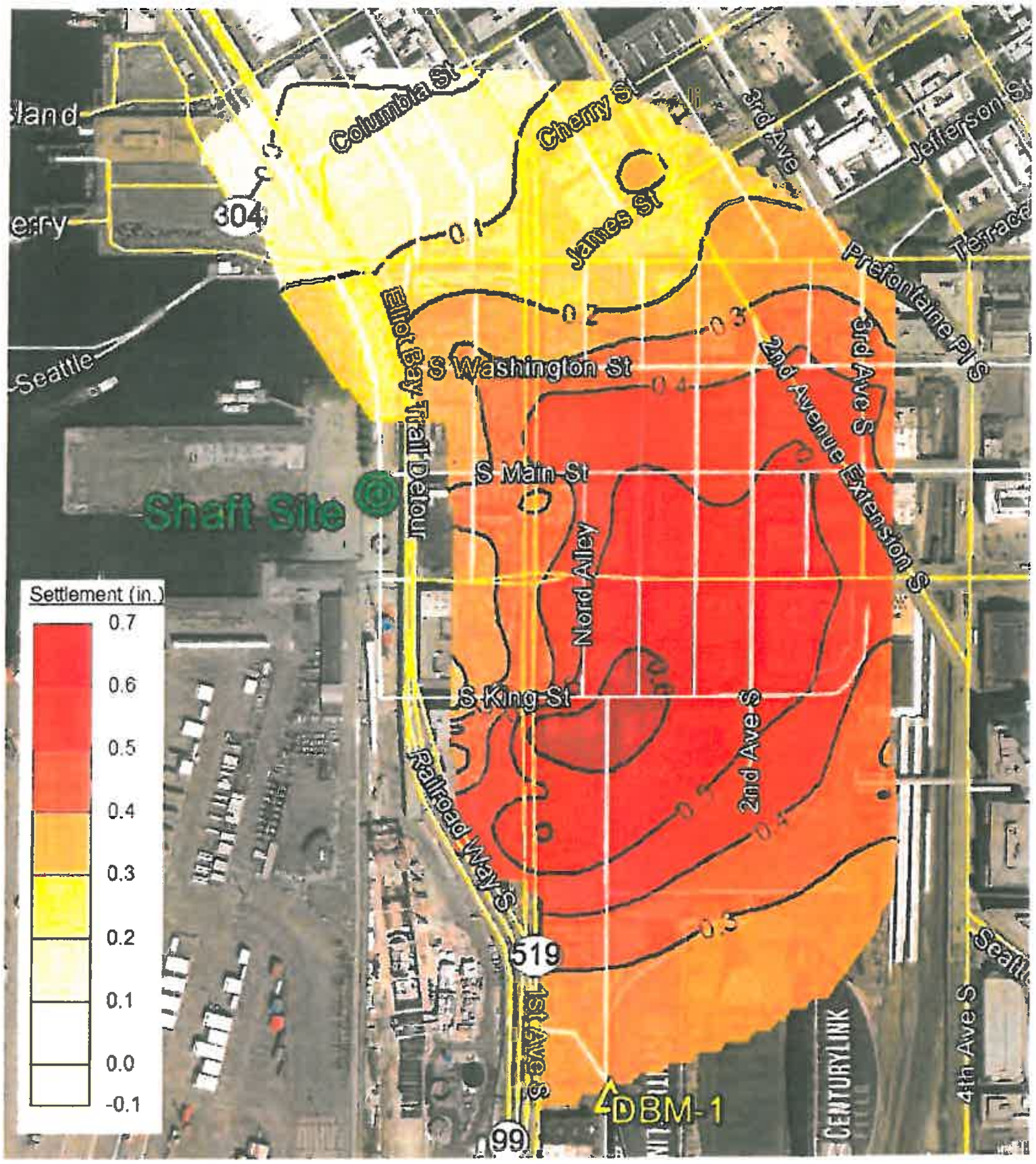
We find that the settlement associated with dewatering at the Access Shaft should be on the order of 0.25-in. and should be centered and localized at the Access Shaft. This estimate is supported by the survey data collected to date. Further, if the settlement reported in Pioneer Square is a result of the dewatering efforts at the Access Shaft then the stiffness of the underlying aquifer would need to be so soft as to be materially different from those baselined in the GBR. This material difference is not supported by the survey data collected to date at the Access Shaft or at the Enwave Seattle well location.

Much of Pioneer Square is constructed on top of tidal flats and tidal marshes as shown in Figure 10. These tidal deposits are susceptible to ongoing subsidence issues as new construction imposes additional loads on these unconsolidated soils and through secondary compression of the highly compressible soils. In addition, much of the fill placed on top of these tidal deposits was uncontrolled fill whose makeup and level of compaction is generally unknown. This uncontrolled fill likely compounds the effects from the tidal deposits. Ongoing subsidence is evident in the regular changes to State and City benchmarks throughout the region.

We understand that the City has reported that a 109 year old 20-in. water line running along Western Avenue has been damaged by settlement allegedly related to dewatering at the Access Shaft. Based on the above, we note that dewatering related settlement could not have caused significant settlement along Western Avenue. In addition, we understand that WSDOT's LIDAR survey of Western Avenue indicates that the street experienced roughly 3-in. of subsidence from 2010 to 2013 and that the subsidence was concentrated at the intersection of Marion and Western. Figure 6 shows deformation, as reported in the ATLAS reports, to be relatively uniform along Western Avenue. It is unlikely that a water line located along a street that has experienced localized subsidence of at least 3-in. was damaged by relatively uniform regional settlement and even less likely that it was damaged by the small component of this settlement related to dewatering at the Access Shaft.

The highest points of settlement are located to the east and south of the Access Shaft. Settlements are likely larger in these areas because the subsurface is composed of softer materials located in estuarial and tidal areas, as shown on Figure 10. These areas are likely still consolidating under their own weight and additional surcharges imparted by new construction. This consolidation likely plays an important role in the regional settlement that has been measured by instrumentation readings that pre-date the Access Shaft work and that has been reported by property owners as a historic phenomenon.

Attachments: Figures 1 through 10
Appendix A – WSDOT and S&W Settlement Figures
Appendix B – Brierley November 25, 2014 Settlement Calculations
Appendix C – Brierley January 9, 2015 Technical Memorandum
Appendix D – Brierley December 10, 2014 Technical Memorandum
Appendix E – 2nd and King Daily Dewatering Report



Contours of Settlement Derived from processed inSAR data as reported by Soldata (Dec. 22, 2014)

Settlement from 10/4/2014 to 12/7/2014 shown based on inSAR data available to us on December 22, 2014

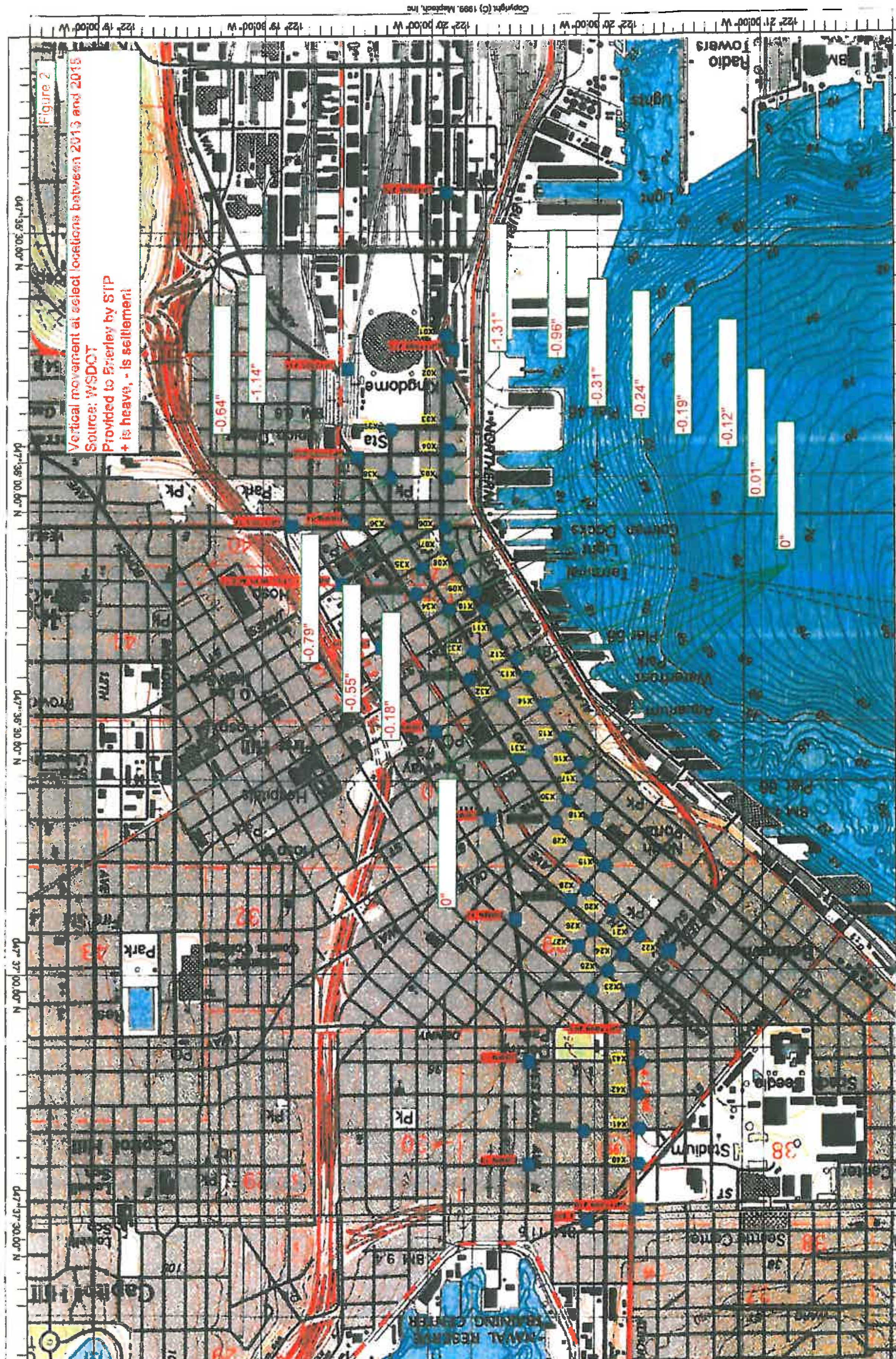
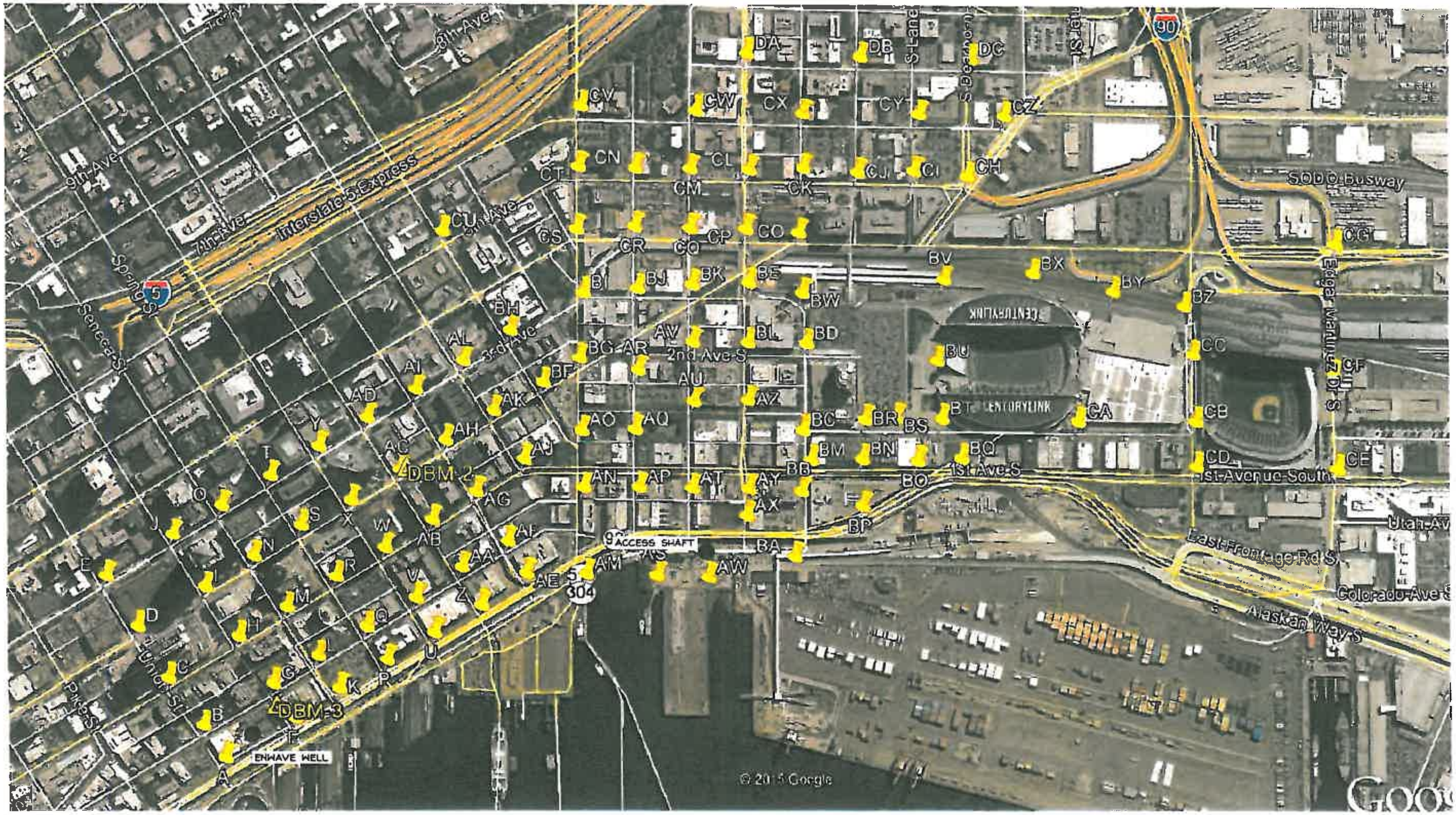


Figure 2
Vertical movement at select locations between 2013 and 2015
Source: WSDOT
Provided to Brierley by STP
+ is heave, - is settlement
-0.64"
-1.14"
-1.31"
-0.96"
-0.31"
-0.24"
-0.19"
-0.12"
0.01"
0"
-0.79"
-0.55"
-0.18"
0"
Kingdome
Copyright (C) 1999, Maptech, Inc



SCALE 500' 0 250' 500'

BRIERLEY ASSOCIATES *Creating Space Underground*	SEATTLE TUNNEL PARTNERS SR 99 ACCESS SHAFT SEATTLE, WASHINGTON	REPRESENTATIVE POINTS LAYOUT	3

SCALE 500' 0 250' 500'

N

BRIERLEY ASSOCIATES
Creating Space Underground

CLIENT	FIGURE TITLE	FIGURE
SEATTLE TUNNEL PARTNERS	REPORTED ATLAS MOVEMENT JULY 2012 TO FEBRUARY 9, 2015 FROM SOLDATA ATLAS REPORT	4
SR 99 ACCESS SHAFT SEATTLE, WASHINGTON		

BRIERLEY ASSOCIATES *Creating Space Underground*	SEATTLE TUNNEL PARTNERS SR 99 ACCESS SHAFT SEATTLE, WASHINGTON	REPORTED SURFACE MOVEMENT JULY 2012 TO NOVEMBER 5, 2014 FROM SOLDATA ATLAS REPORT	5

SCALE 500' 0 250' 500'

BRIERLEY ASSOCIATES *Creating Space Underground*	CLIENT: SEATTLE TUNNEL PARTNERS SR 99 ACCESS SHAFT SEATTLE, WASHINGTON	FIGURE TITLE: REPORTED SURFACE MOVEMENT NOVEMBER 5, 2014 TO DECEMBER 7, 2014 FROM SOLDATA ATLAS REPORT	FIGURE: 6

BRIERLEY ASSOCIATES *Creating Space Underground*	CLIENT: SEATTLE TUNNEL PARTNERS PROJECT NO. 114919-007 SR 99 ACCESS SHAFT SEATTLE, WASHINGTON	FIGURE TITLE: REPORTED SURFACE MOVEMENT DECEMBER 7, 2014 TO FEBRUARY 9, 2015 FROM SOLDATA ATLAS REPORT	FIGURE: 7

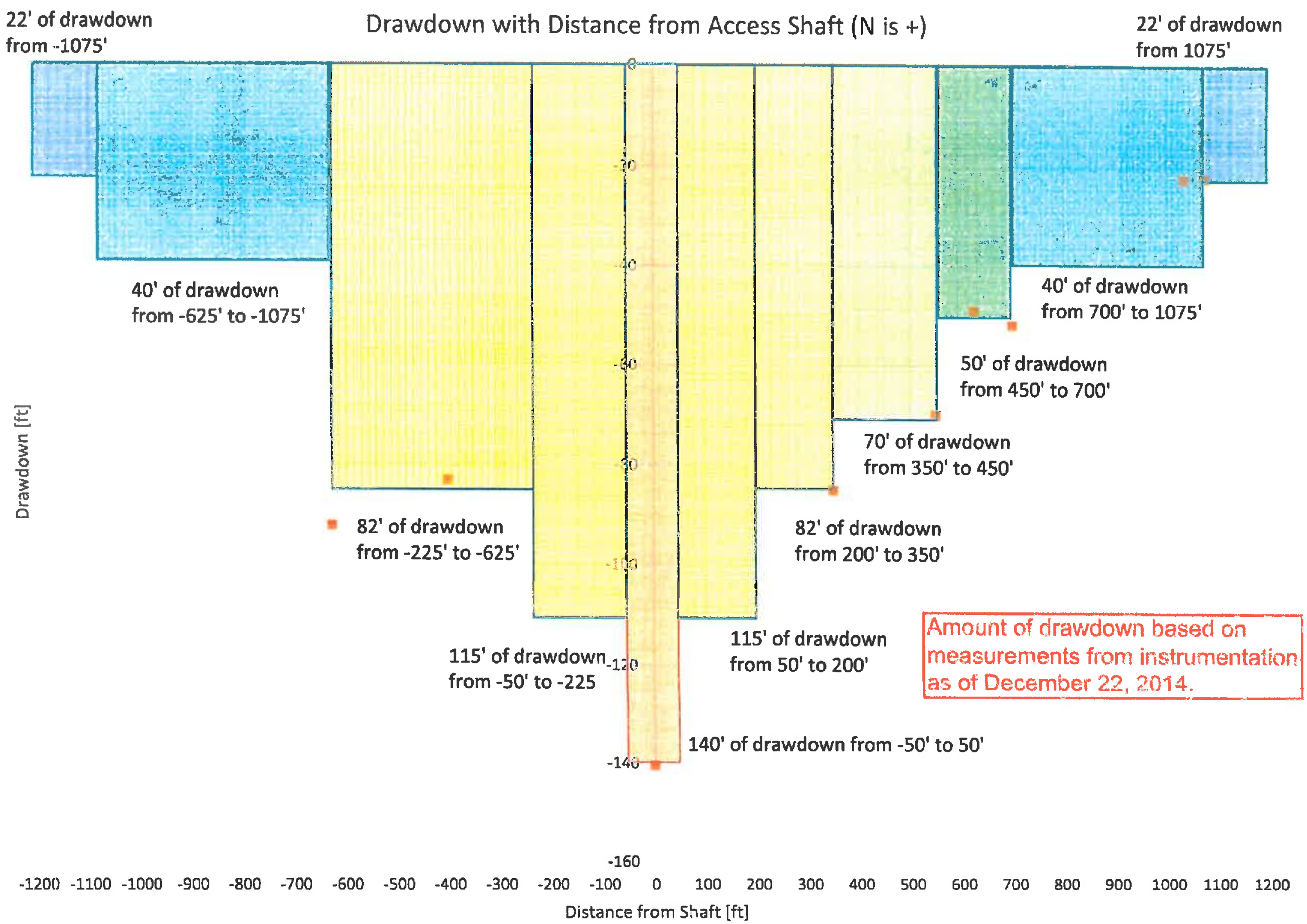
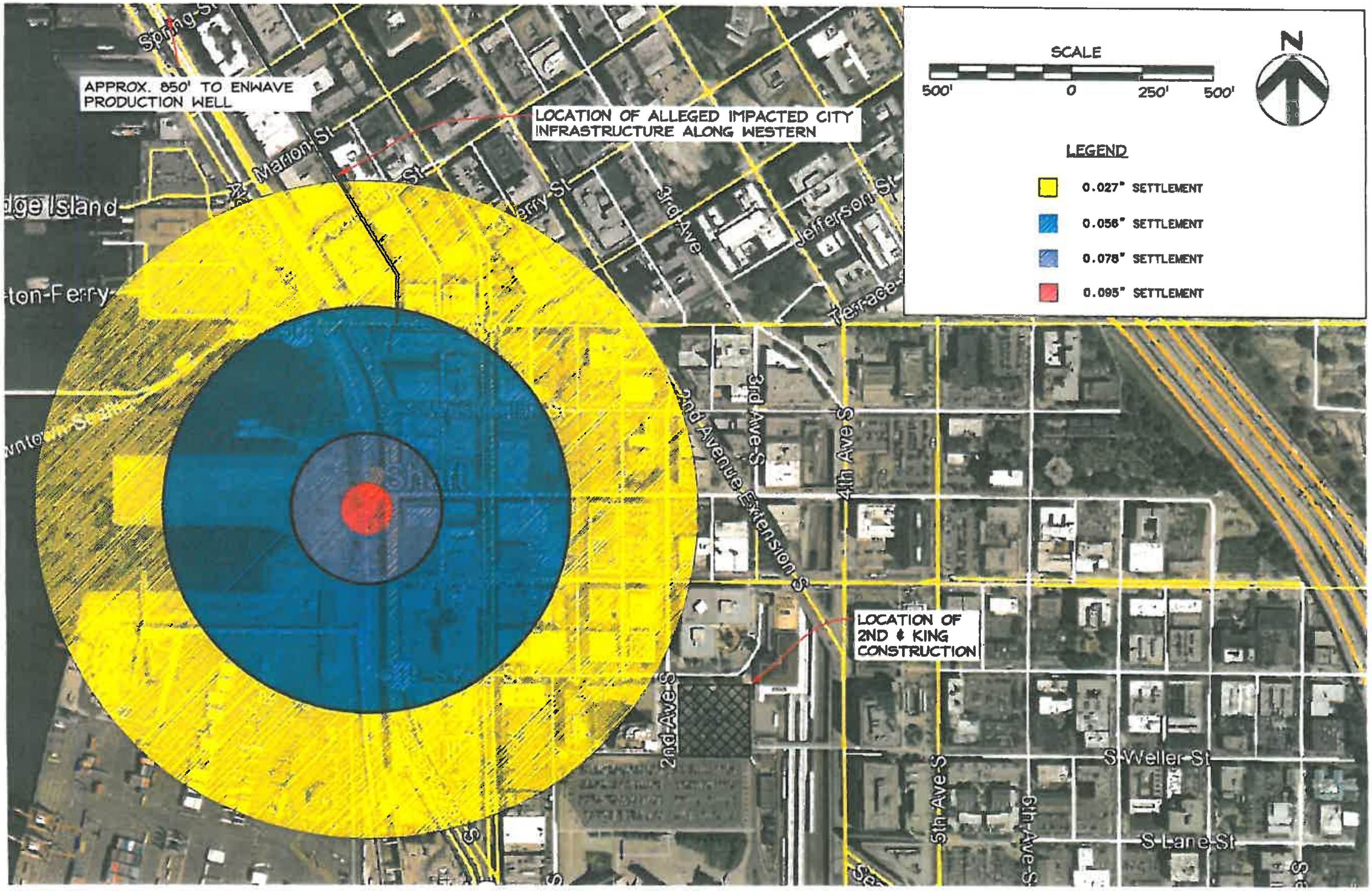
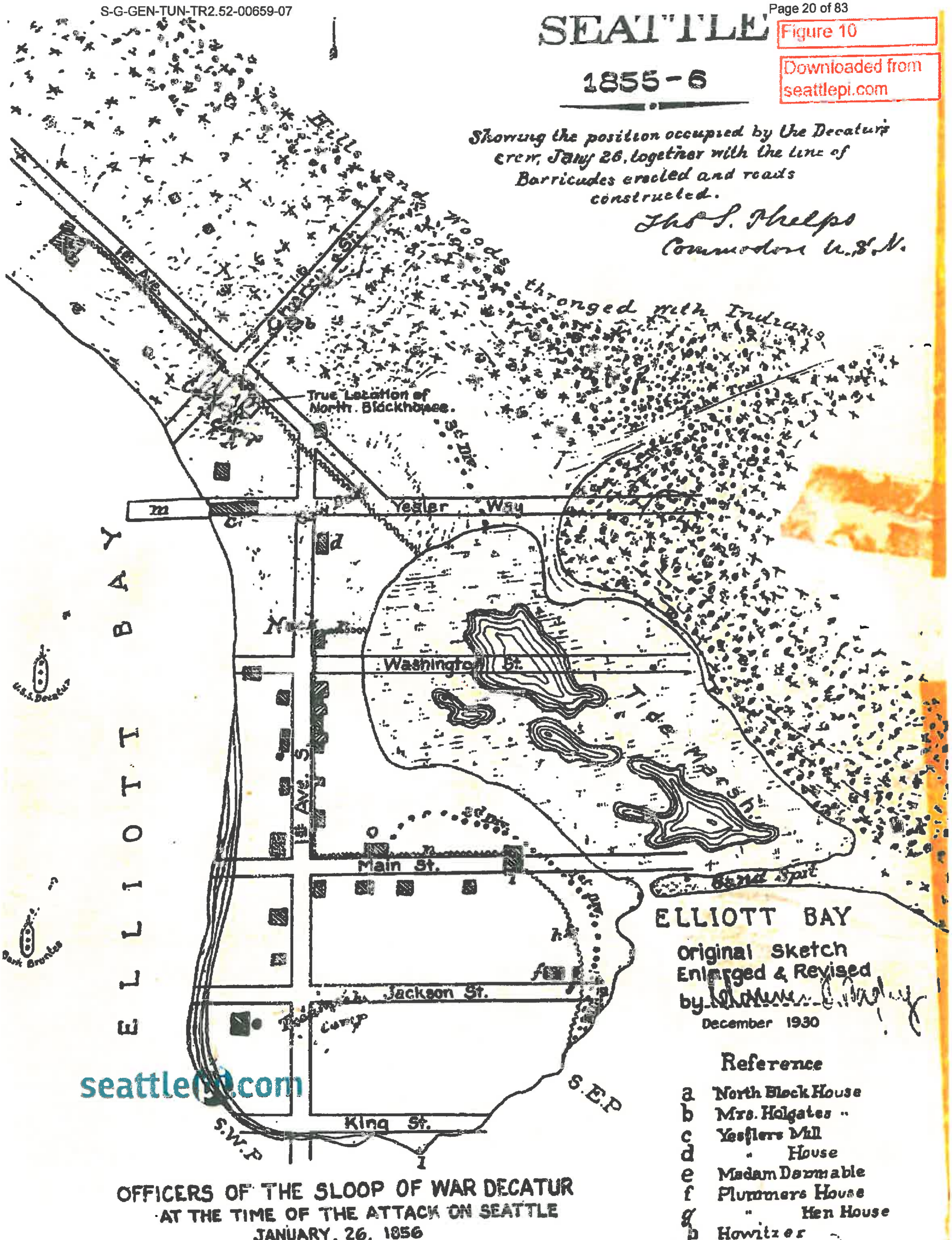

Drawdown with Distance from Access Shaft (N is +)
22' of drawdown from -1075'
40' of drawdown from -625' to -1075'
82' of drawdown from -225' to -625'
115' of drawdown from -50' to -225
140' of drawdown from -50' to 50'
115' of drawdown from 50' to 200'
82' of drawdown from 200' to 350'
70' of drawdown from 350' to 450'
50' of drawdown from 450' to 700'
40' of drawdown from 700' to 1075'
22' of drawdown from 1075'
Amount of drawdown based on measurements from instrumentation as of December 22, 2014.
Drawdown [ft]
0
-140
-160
-1200 -1100 -1000 -900 -800 -700 -600 -500 -400 -300 -200 -100 0 100 200 300 400 500 600 700 800 900 1000 1100 1200
Distance from Shaft [ft]

Figure 8



BRIERLEY ASSOCIATES *Creating Space Underground*	CLIENT: SEATTLE TUNNEL PARTNERS PROJECT NO. 114010-007: SR 99 ACCESS SHAFT SEATTLE, WASHINGTON	FIGURE TITLE: ESTIMATED SURFACE MOVEMENT DUE TO DEPRESSURIZATION OF LOWER AQUIFER BASED ON DRAWDOWN CURVE OBSERVED IN INSTRUMENTATION AS OF DECEMBER 22, 2014	FIGURE: 9

Figure 10


SEATTLE
1855-6
Showing the position occupied by the Decatur's crew, Jany 26, together with the line of Barricades erected and roads constructed.
Thos S. Phelps
Commodore U.S.N.
Hills and Woods thronged with Indians
True Location of North Blockhouse
Yesler Way
Washington St.
Main St.
Jackson St.
King St.
1st Ave.
1st Ave. S.
Tide Marsh
Sand Spit
ELLIOTT BAY
ELLIOTT BAY
U.S.S. Decatur
Bark Bronte
S.E.P
S.W.P
Trail
Original Sketch
Enlarged & Revised
by
December 1930
Reference
a North Block House
b Mrs. Holgates "
c Yeslers Mill
d " House
e Madam Damnable
f Plummers House
g " Hen House
h Howitzer
OFFICERS OF THE SLOOP OF WAR DECATUR
AT THE TIME OF THE ATTACK ON SEATTLE
JANUARY. 26. 1856

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Appendix A: WSDOT and S&W Settlement Figures

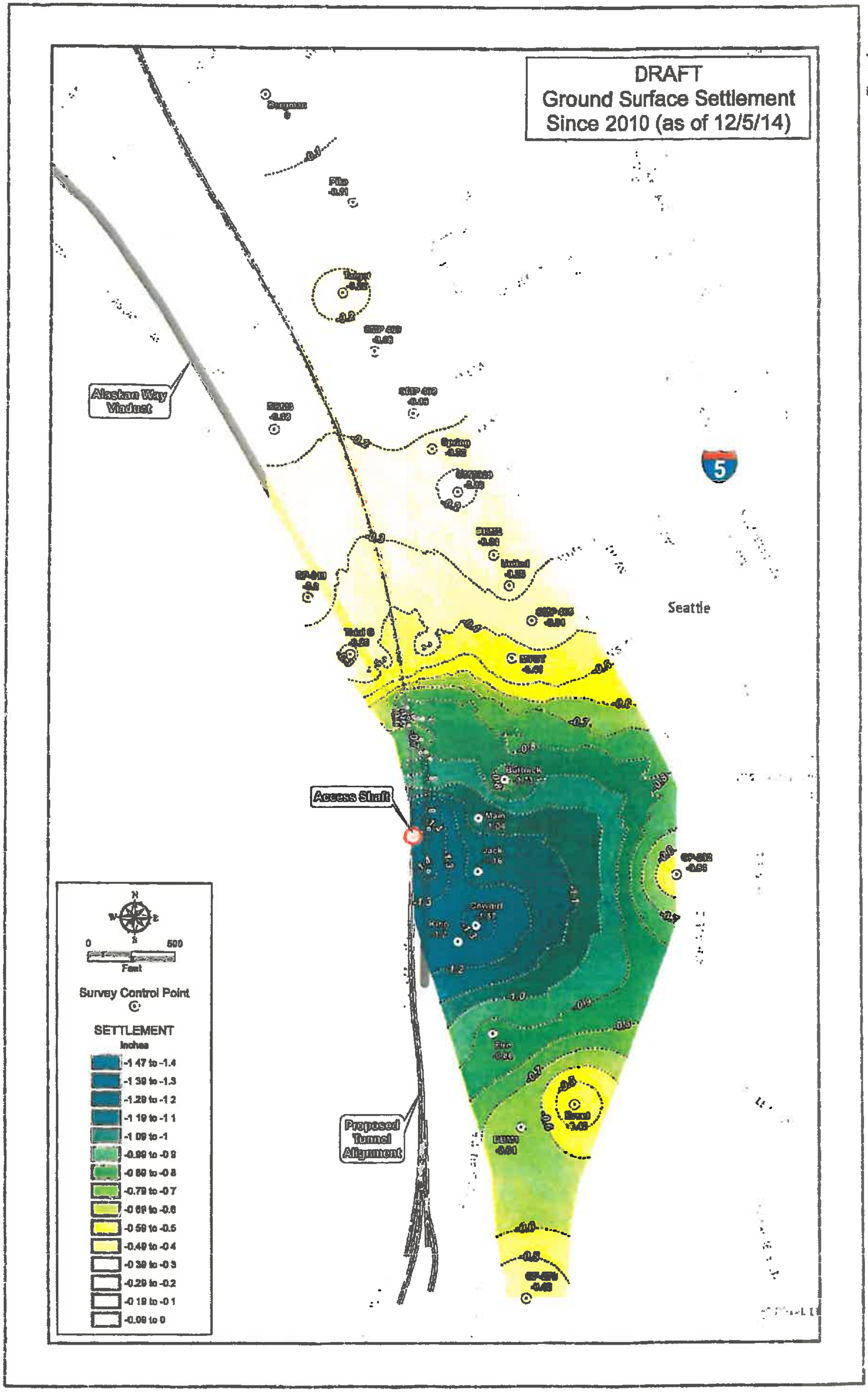
DRAFT
Ground Surface Settlement
Since 2010 (as of 12/5/14)
Alaskan Way Viaduct
Seattle
Access Shaft
Proposed Tunnel Alignment
5
0
500
Feet
Survey Control Point
SETTLEMENT
Inches
-1.47 to -1.4
-1.39 to -1.3
-1.29 to -1.2
-1.19 to -1.1
-1.09 to -1
-0.99 to -0.9
-0.89 to -0.8
-0.79 to -0.7
-0.69 to -0.6
-0.59 to -0.5
-0.49 to -0.4
-0.39 to -0.3
-0.29 to -0.2
-0.19 to -0.1
-0.09 to 0

Figure 1

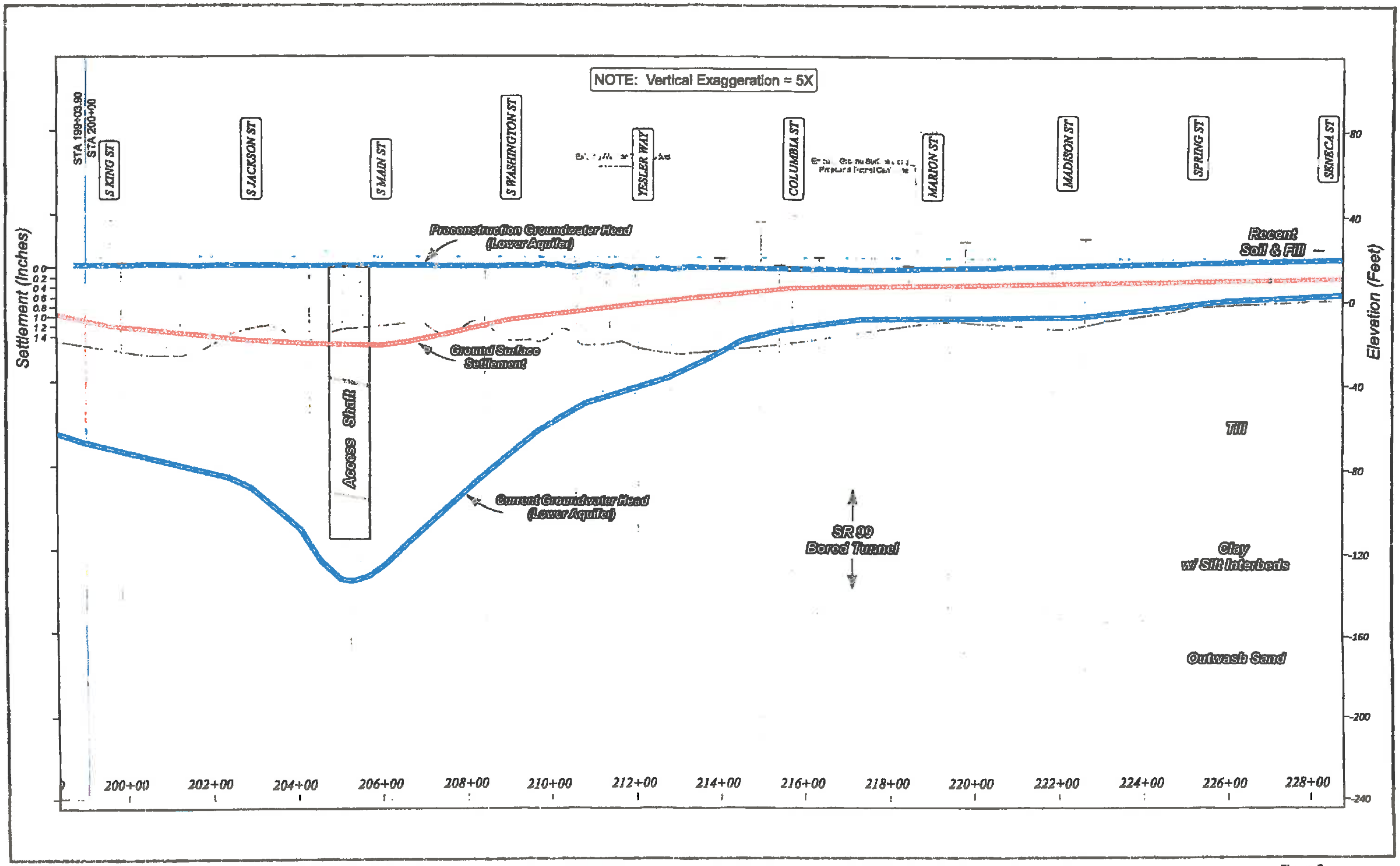
NOTE: Vertical Exaggeration = 5X
STA 199+03.90
STA 200+00
S KING ST
S JACKSON ST
S MAIN ST
S WASHINGTON ST
YESLER WAY
COLUMBIA ST
MARION ST
MADISON ST
SPRING ST
SENECA ST
Preconstruction Groundwater Head (Lower Aquifer)
Ground Surface Settlement
Current Groundwater Head (Lower Aquifer)
Access Shaft
SR 99 Bored Tunnel
Recent Soil & Fill
Till
Clay w/ Silt Interbeds
Outwash Sand
Settlement (Inches)
Elevation (Feet)
200+00
202+00
204+00
206+00
208+00
210+00
212+00
214+00
216+00
218+00
220+00
222+00
224+00
226+00
228+00

Figure 2

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Appendix B: Brierley November 25, 2014 Settlement Calculations

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Job No. 114010-004 Date 11/25/14 Page 1 of 5
By ATM Checked GWP Rev
Client STP
Project SR 99 ACCESS SHAFT
Subject DEWATERING INDUCED SETTLEMENT

SOIL PROPERTIES

STRATA	G_{ur} (KSI)	G_{ur} (KSF)	ν	E (KSF)
ESU 1	NA	NA	0.3	864
ESU 4	220	31680	0.4	88704
ESU 5	170	24480	0.35	66096
ESU 6	50	7200	0.4	20160
ESU 7	60	8640	0.45	25056

$\Delta S_i = \frac{\Delta U}{E}(t)$

$S_{tot_i} = \Sigma \Delta S$

ESTIMATED SETTLEMENT h_p ON 11/24/14

PZ No.	h_{p_i} (FT)	h_p (FT)	ΔU (PSF)	E (KSF)	t (FT)	ΔS_i (IN.)	S_{tot} (IN.)	
PZ5-9	7	4	187	864	20	0.05		
PZ5-54	-1	-41	2496	66096	30	0.01		
PZ5-86	-3	-48	2808	66096	20	0.01	.185	
PZ5-129	-20	-88	4243	20160	45	0.11	0.18	0.2"
PZ6-9	6	4	125	864	20	0.03		
PZ6-54	1	-18	1186	66096	30	0.01		
PZ6-84	2	-18	1248	66096	20	0.01		
PZ6-149	6	-132	8611	66096	50[1]	0.08	0.13	0.2"
PZ7-19	9	5	250	864	20	0.07		
PZ7-54	6	-40	2870	66096	30	0.02		
PZ7-87	4	-48	3245	66096	20	0.01		
PZ7-134	-6	-85	4930	20160	20	0.06	0.16	0.2"

S < 0.25 IN. @ PZ 5 PZ 6 & PZ 7 @ GROUND SURFACE

(1) ESTIMATED THICKNESS

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Job No. 114010-004 Date 11/25/14 Page 2 of 5
By KJM Checked GWP Rev
Client STP
Project SR 99 ACCESS SHAFT
Subject DEWATERING INDUCED SETTLEMENT

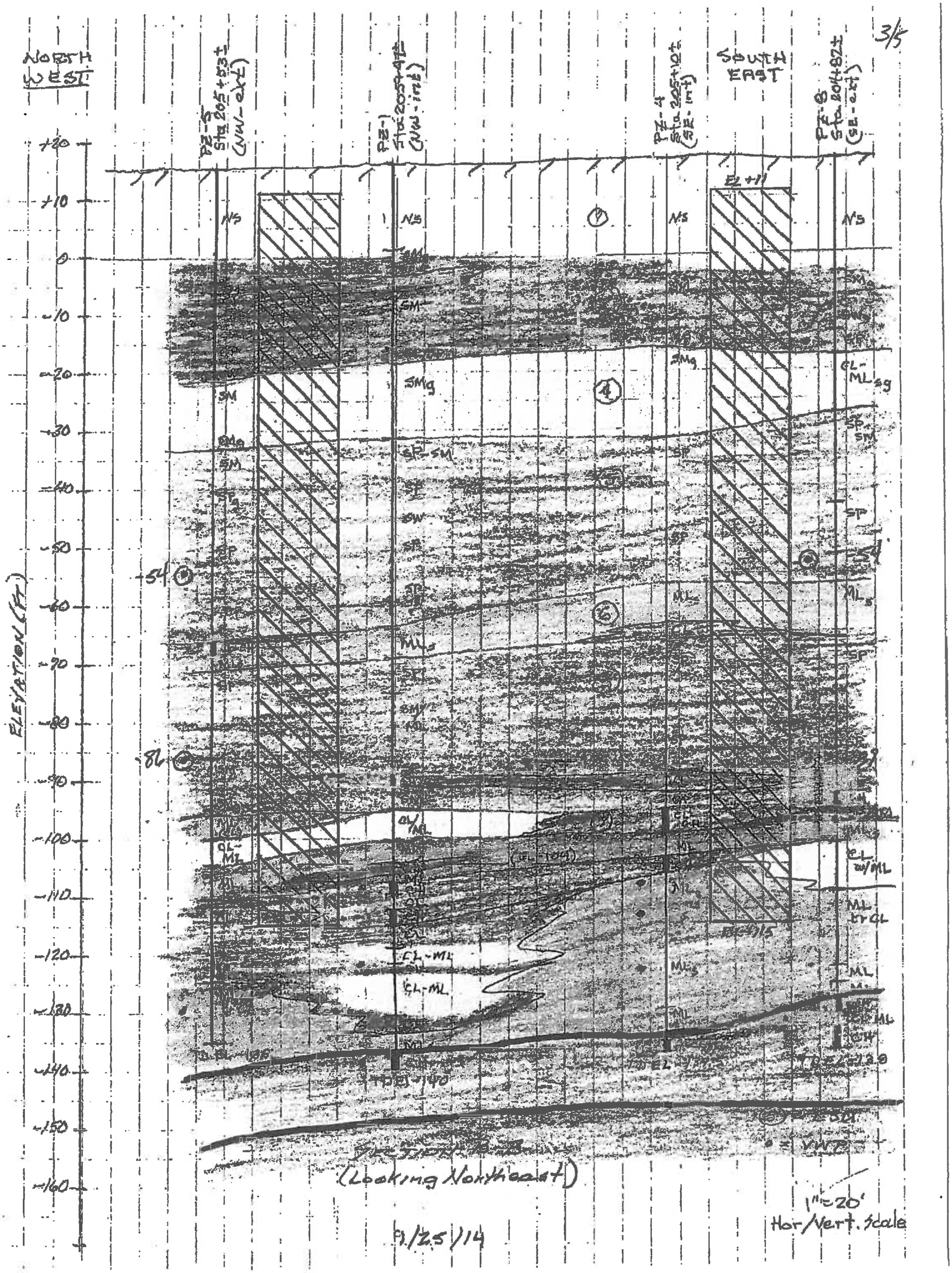
ESTIMATED SETTLEMENT h_P ON 11/24/14

PZ No.	h_{Pi} (FT)	h_P (FT)	ΔH (PSF)	E (KSF)	t (FT)	ΔS (IN.)	S_{TOT} (IN.)	
PZ8-16	3	-4	437	864	20	0.12		
PZ8-64	-1	-19	1123	66096	30	0.01		
PZ8-89	2	-22	1498	66096	20	0.01		
PZ8-124	-11	-98	5429	20160	30	0.10	0.24	0.25"
PZ14-2	5	3	125	864	20	0.03		
PZ14-52	1	-19	1248	66096	30	0.01		
PZ14-84	-1	-36	2184	66096	20	0.01 0.10(2)	0.15	0.2"
DPM1-119	-4	-85	5064	20160	35	0.10		
DPM1-134	6	-111	7301	25056	15	0.05		
DPM1-169	10	-125	8424	66096	50(1)	0.08	0.23	0.25"
TB324-1	8	5	187	864	20	0.05		
TB324-44	-5	-15	624	66096	30	0.01		
TB324-79	-5	-15	624	66096	20	0.01	0.07	0.10"
UB103-49	0	-17	1061	66096	30	0.01		
UB103-84	0	-21	1310	66096	20	0.01	0.02	0.10"
CB107-10	5	3	125	864	20	0.03		
CB107-85	0	-17	1061	66096	20	0.01		
CB107-155	8	-75	5179	66096	50(1)	0.05	0.09	0.10"

S < 0.25 IN. @ PZ8, PZ14, DPM1, TB324, UB103, & CB107 @ G.S.

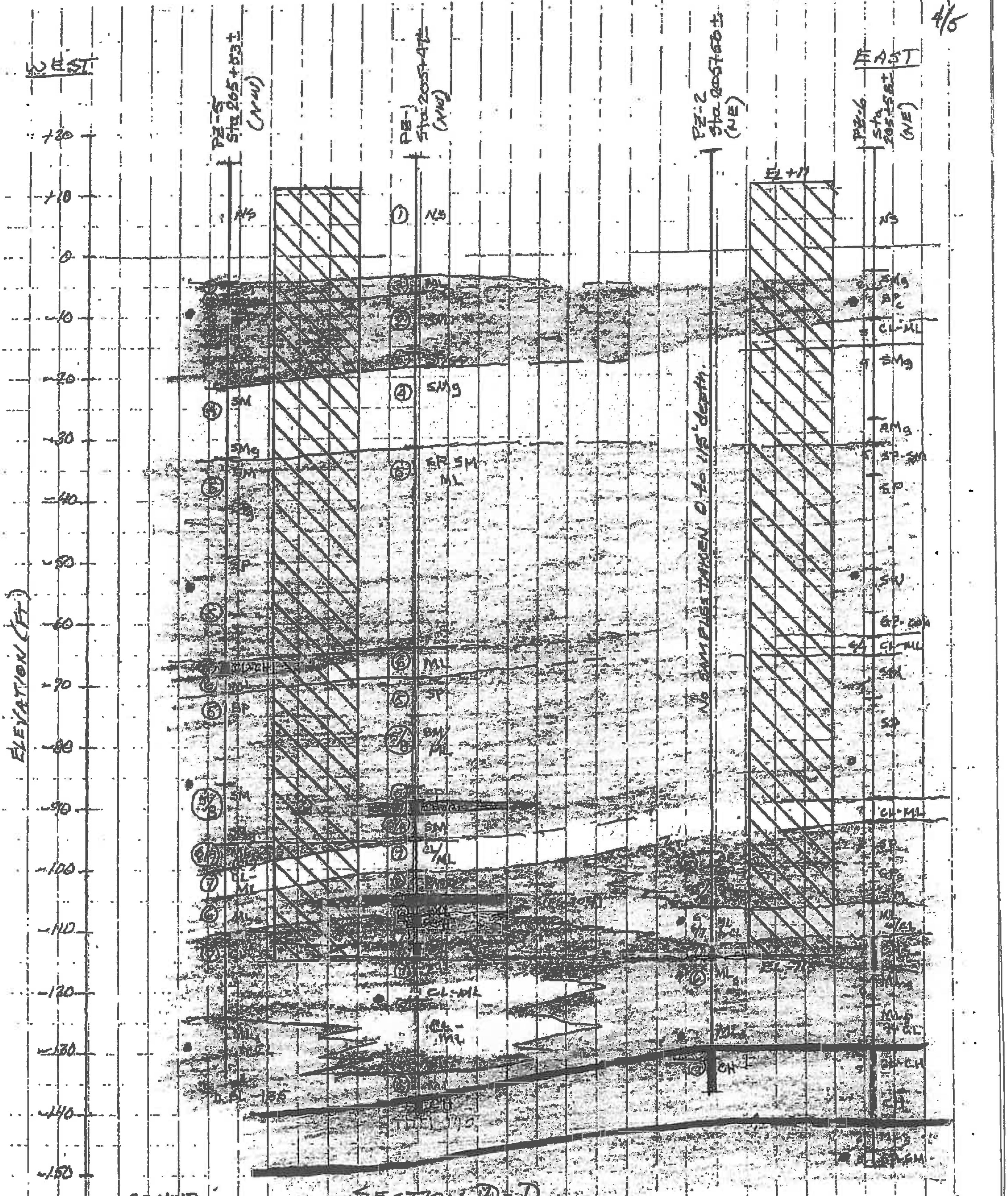
(1) ESTIMATED THICKNESS
(2) ESTIMATED SETTLEMENT

ESTIMATED SETTLEMENT OF AWV S < 0.20 IN.


3/5
NORTH WEST
SOUTH EAST
PZ-5 Sta 205+03± (NW-ext)
PZ-1 Sta 205+48± (NW-int)
PZ-4 Sta 205+10± (SE-int)
PZ-8 Sta 204+82± (SE-ext)
ELEVATION (FT)
+20
+10
0
-10
-20
-30
-40
-50
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
-160
EL +11
-54
-86
(Looking Northeast)
1"=20'
Hor/Vert. Scale

11/25/14

4/5



SECTION D-D

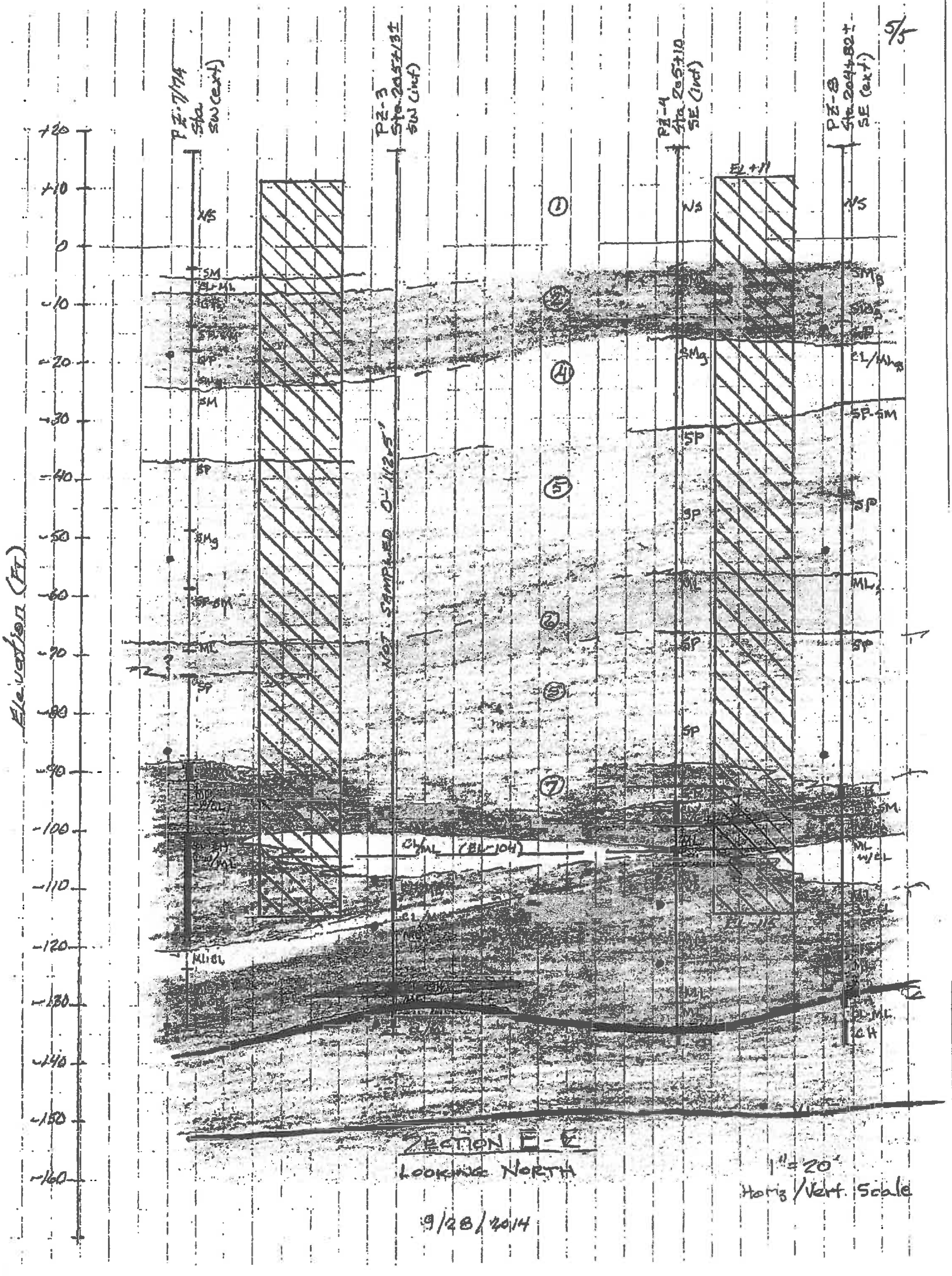
NORTH END OF SHAFT

LOOKING NORTH

9/19/2014

1" = 20'

Hor/Vert. Scale


5/5
Elevation (FT)
PZ-7/7A Sta SW (ext)
PZ-3 Sta 2057+31 SW (int)
PZ-4 Sta 2057+10 SE (int)
PZ-8 Sta 2044+82± SE (ext)
EL+11
EL-116
NOT SAMPLED 0'-112.5'
CL/ML (BL-104)
SECTION E-E
LOOKING NORTH
1" = 20'
Horiz/Vert. Scale
9/28/2014

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Appendix C: Brierley January 9, 2015 Technical Memorandum

BRIERLEY ASSOCIATES
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TECHNICAL MEMORANDUM

Date: January 9, 2014

To: Chris Dixon, Project Manager
Seattle Tunnel Partners

Cc: AJ McGinn, Brierley Associates
Eric Lindquist, Brierley Associates

From: Patrick M. Smith, PhD, PE, GE, Brierley Associates
Jacob Mitchell, PE, Brierley Associates

Re: Ground Settlement from Dewatering during Shaft Construction
SR99 TBM Access Shaft
Seattle, WA

This memorandum presents our review and interpretation of ground deformation that has been attributed to dewatering activities at the SR99 recovery shaft. Figures 1 and 2 present ground deformations associated with dewatering as defined by Shannon & Wilson (S&W). Much of the reported settlement to date within the region has been attributed to Seattle Tunnel Partner's (STP's) dewatering of a confined aquifer with little to no supporting data other than manual leveling survey loops from pre-defined benchmarks.

We understand that Figures 1 and 2 were developed by S&W, but are unsure of the data source used to develop the reported settlements (e.g. WSDOT, City of Seattle, STP, etc.). STP has an enormous amount of ground deformation data that can be used to refute S&W's interpretations, which we believe are erroneous and were presented prematurely prior to vetting of the survey data and comparison to subsurface conditions. Proper interpretation of the deformation data requires detailed review and comparison to settlement estimates based on actual geotechnical conditions. To date, we do not believe a proper interpretation of the data has been performed by S&W and the raw, unchecked data is instead just being reported.

Our work in development of this memorandum included: 1) an initial review and interpretation of geotechnical conditions near the shaft and at selected locations; 2) review of subsurface monitoring data; 3) estimates of settlement associated with dewatering at noted locations; and, 4) review of terrestrial survey and inSAR data. As more data becomes available, the findings in this memorandum will be updated.

In short, the interpretation of the data and findings summarized herein clearly refutes S&W's and WSDOT's conclusion that dewatering at the Access Shaft and intervention site has induced settlement above the threshold and limiting values for the project. Based on these findings, STP should request a retraction of S&W's and WSDOT's reported settlements to date until all of the data used to measure and estimate settlements has been properly checked and verified.

Current Access Shaft Dewatering System

The dewatering system at the Access Shaft currently consists of sixteen dewatering wells. Five of these wells (DW1, DW2, DW3, DW6, and DW7) are located within the shaft itself and extend to approximately 150 feet in depth to approximately El -135 feet. Four wells (DW4, DW5, DW8, and DW9) are located directly south of the shaft and adjacent to the TBM with two of them extending approximately 150 ft in depth to approximately El -135 feet and two extending to approximately 115 feet in depth to approximately El -99 feet. Three wells (SW1, SW2, and SW3) are located outside of the shaft to the northeast and extend to approximately 150 feet in depth to approximately El -135 feet. Four wells (DDW1, DDW2, DDW3, and DDW4A) extend to approximately 200 feet in depth to approximately El -185 feet.

The DW wells are isolated from the upper aquifers by well seals and an aquitard (see below). The SW wells are located within the soil plug stratum and are isolated from both the upper and lower aquifers by a well seal and an aquitard, respectively. The DDW wells are located in the lower aquifer are and isolated from the upper aquifer by well seals and an overlying aquitard.

The operational history of the dewatering wells is that the interior shaft wells were turned on in or around October while the wells adjacent to the machine were operated intermittently during this same period. The other wells (DDW and SW) were installed in late October. The SW wells were brought online November 4, 2014. The DDW wells, except for DDW4, were brought online on November 8, 2014. Various components of the system had been tested and used prior to this intermittently. Since November 8, 2014, the system has run continuously with only short downtimes for maintenance issues. DDW4 had issues and so was replaced by DDW4A on November 20, 2014.

Subsurface Conditions at the SR99 Recovery Shaft

Subsurface materials. Subsurface material composition has been interpreted using information contained within project geotechnical reports (e.g. GBR and GDR), and from boring logs and subsurface instrumentation locations near the shaft. A simplified profile, in comparison to those used for shaft design, is used for assessment of settlement associated with depressurization of the deep aquifer at the shaft site. Table 1 presents the simplified profile:

Table 1. Simplified Subsurface Profile for Dewatering Related Settlement Analysis

Description	Top Elevation (ft)	Lower Elevation (ft)	Unload Reload Modulus (ksi)
Soils Overlying Aquifer	+15	-140	N/A
Overlying Aquitard	-140	-150	N/A
Permeable Aquifer	-150	-180 to -210	170
Lower Aquitard	-180 to -210	-335	170

The aquifer thickness in the vicinity of the shaft is estimated as 30 feet, which is consistent with soils encountered at deep well locations and GBR geologic profile at Sta. 211+50. However, it is possible the aquifer could be up to 60 feet thick based on review of GBR geologic profile south of the shaft and borehole log for deep monitoring point DPM-1 which is located approximately 60 feet west of the Access Shaft at Sta. 205+25 (see Attachment A for borehole logs). The difference in aquifer thickness is reflected in the range of elevations between the Permeable Aquifer and Lower Aquitard Boundary as presented in Table 1.

To be consistent with the GBR, properties within the Permeable Aquifer are assumed to be consistent with those for ESU-05. Also, underlying materials are assumed to have similar properties because there is very little subsurface insitu testing data within the shaft area for subsurface materials below El. -160 feet.

Materials below El. -335 feet are assumed to be incompressible, which is consistent with subsurface profile EB-18B (see Attachment B) used in the Alaskan Way Viaduct and Seawall Project Seismic Ground Motion Study Seattle, Washington (Shannon & Wilson, 2004). We consider this an appropriate assumption considering soil moduli would increase with depth and any potential dewatering induced strains at these depths would decrease; thus, deformation would decrease exponentially with depth.

Groundwater Depressurization. The amount of depressurization within the confined aquifer is estimated from readings at vibrating wire and standpipe piezometers from November 4th to date. All measurements used were taken from instruments that are located over 150 feet below existing grade and interpreted to be embedded within the confined aquifer. Table 2 summarizes the instrument locations reviewed and provides estimates of drawdown within the confined aquifer.

Table 2. Piezometer and Standpipe Piezometers

Number	Type	Street	Sta.	Instrument Depth (ft)	Pressure (ft)		
					Before Dewatering	Near Dec. 15, 2014	Calculated Drawdown
TB-104	VWP	King St	199+75	174	2	-90	92
EB-18B	VWP	Alaskan Way	201+30	219	6	-77	83
DPM-1	VWP	Alaskan Way	205+26	185	11	-130	140
CB-107	VWP	Alaskan Way	208+40	168.5	8	-77	85
CB-106	VWP	Alaskan Way	210+45	159	17	-53	70
TB-321	Standpipe	Alaskan Way	211+37	156 to 166	4	-45	49
PZ 126	VWP	Yesler Way	212+00	159	9	-43	52
TB-319	Standpipe	Western Ave	215+38	174 to 184	13	-10	22
PZ 127	VWP	Columbia St	215+70	173	11	-11	22

The piezometers extend laterally over 1000 feet to the north and south of the shaft, so the change in pressure due to dewatering can be estimated laterally. Figure 4 presents the interpreted drawdown due to dewatering in the confined aquifer with respect to the shaft. Also shown on Figure 4 are the calculated drawdowns provided in Table 2.

This trend in depressurization with distance somewhat corresponds with the findings from S&W (Figure 2), but the magnitudes we calculate are generally lower by 5 to 10 feet. S&W's groundwater level profile is also asymmetric, with increased drawdown to the south. This may be due to the assumption of a constant pre-construction groundwater level over much of the aquifer rather than calculating the change in head pressure solely over the period of dewatering.

<u>Settlement Estimates at the SR99 Recovery Shaft</u>

Estimates of settlements at the shaft site are made for the following conditions:

1. Depressurization of the 30 to 60 feet thick aquifer only.
2. Depressurization of the 30 to 60 feet thick aquifer and increase in effective stress in soils below the aquifer from a vertical load equivalent to the change in pressures as shown in Fig 4.

For Condition 1, we assume that no leakage occurs across the aquitard boundaries and the axial strains are equivalent to the drop in head (135 feet from review of Figure 4) from dewatering times an appropriate moduli value. The settlement is then taken as thickness of the aquifer times the calculated axial strain.

Condition 2 is used to include settlements assuming the depressurization of the overlying confined aquifer results an increase in vertical stress in the underlying soils. This is consistent with the hypothesis postulated by S&W during our initial conference call with them on December 12th. As stated then, we do not agree with this hypothesis, but have included results of this analysis for comparative purposes.

The increase in vertical stress is calculated using the Wesgtergaard method as encoded in ZSTRESS, commercially available software, and assuming the change in head to the north of the shaft acts as concentric loads about the center of the shaft. The axial strains are calculated using an appropriate modulus times the change in vertical stress then integrated over depth to calculate settlement below the aquifer. The resulting settlement is added to that calculated in Condition 1 to estimate the total settlement for Condition 2.

We note Condition 2 is unlikely to occur because the vertical stress in the soils below the confined aquifer will remain relatively unchanged due to dewatering because: 1) there is not an increase in vertical load due to dewatering, and 2) dewatering in the deep confined aquifer does not change the pore pressure at depth. In fact, a reduction in vertical stress will occur at and near the shaft as a result of excavation activities, but this is ignored in the analysis for sake of simplicity.

Constrained and Young's moduli are used to calculate axial strains for comparative purposes, but the constrained modulus is the more suitable parameter to use in these estimates because lateral movement is confined. The moduli are calculated using the undrained-reload shear modulus of 170 ksi, the baseline value for ESU 5, and a Poisson's ratio of 0.35.

Estimated settlements for soils above the confined aquifer are taken from review of extensometer monitoring data at the shaft (MPBX128). As shown on Figure 4, a drawdown of 140 feet was measured near the shaft and used in the analysis. Readings from this nearby extensometer that extends from near the surface to the top of the lower confined aquifer at the shaft indicates settlement during dewatering are on the order of 0.1 inch (Figure 5). The estimated total settlements for Condition 1 and 2 are provided in Table 2 with calculations supplied in Attachment C.

Table 3. Calculated Settlements at the Access Shaft (in.)

Description	30 ft. Thick Aquifer		60 ft. Thick Aquifer	
	Constrained Modulus	Young's Modulus	Constrained Modulus	Young's Modulus
Overlying Soils	0.1	0.1	0.1	0.1
Confined Aquifer	0.03	0.05	0.06	0.09
Total Condition 1	**0.13**	**0.15**	**0.16**	**0.20**
Below Aquifer	0.12	0.20	0.10	0.16
Total Condition 2	**0.25**	**0.35**	**0.26**	**0.36**

Neglecting settlement in soils below the aquifer indicates settlements at the shaft site are on the order of 0.2 inch or less (Table 2). These estimated settlements are significantly less and inconsistent with the reported settlement of 1.4 inch, as presented by S&W and WSDOT. Additionally, variations in aquifer thickness and modulus type (i.e. – Constrained versus Young's) have a minimal effect on total calculated settlements.

Settlement Estimates at Other Locations

Settlements for Condition 1 and 2 are calculated for two locations where manual survey points are present and monitored, significant settlements have been presented by S&W and WSDOT, sufficient subsurface data was available to infer the depth of the aquifer, and extensometer data was available to estimate settlement of overlying soils. These locations are the intersection of Yesler Way and Alaskan Way and Cowgirls Bar monitoring point located at 1st Ave and King Street. Calculations are provided in Attachment C.

Yesler Way and Alaskan Way. The intersection of Yesler Way and Alaskan Way is about 700 feet north of the shaft. An aquifer thickness of 30 and 60 feet that begins about 150 ft below existing grade from review of area borehole logs (~El. -135 ft.) is used in the calculations with a change in pressure of 50 feet (Figure 4). Table 3 summarizes estimated settlements at this location.

Table 4. Calculated Settlements at the Yesler Way and Alaskan Way Intersection (in.)

Description	30 ft. Thick Aquifer		60 ft. Thick Aquifer	
	Constrained Modulus	Young's Modulus	Constrained Modulus	Young's Modulus
Overlying Soils	0.17	0.17	0.17	0.17
Confined Aquifer	0.01	0.02	0.02	0.03
Total Condition 1	**0.20**	**0.22**	**0.19**	**0.20**
Below Aquifer	0.05	0.08	0.04	0.07
Total Condition 2	**0.23**	**0.27**	**0.23**	**0.27**

The settlement in the overlying soils shown in Table 3 was derived from review of extensometer data at MPBX126 (Figure 6).

Neglecting settlement in soils below the aquifer indicates settlements at the intersection should be on the order of 0.2 inch or less. This is significantly less than the 0.7 inch of settlement as presented by S&W and WSDOT at this location.

Cowgirls. The settlements at the Cowgirls monitoring point as presented by S&W and WSDOT in Figure 1 is 1.4 inch. From review of borehole TB 104, it appears the confined aquifer begins at depth of about175 feet below grade (~El. -160). This site is about 625 feet southeast of the shaft and had a change in pressure of around 92 feet over the period of dewatering as calculated from groundwater readings at TB-104 (Table 1). Calculated settlements using this information are presented in the Table 4.

Table 5. Calculated Settlements near Cowgirls (in.)

Description	30 ft. Thick Aquifer		60 ft. Thick Aquifer	
	Constrained Modulus	Young's Modulus	Constrained Modulus	Young's Modulus
Overlying Soils	0.1	0.1	0.1	0.1
Confined Aquifer	0.02	0.03	0.04	0.06
Total Condition 1	**0.12**	**0.13**	**0.14**	**0.16**
Below Aquifer	0.05	0.08	0.04	0.07
Total Condition 2	**0.17**	**0.21**	**0.18**	**0.23**

The settlement in the overlying soils in Table 4 was estimated to be about half the change in vertical measurements at near surface monitoring points in the area of the intersection of Alaska Way and King Street. Although this estimate is ambiguous, it is similar in magnitude from measurements made at the shaft.

Neglecting contribution from underlying soils below the aquifer, the calculated settlements near Cowgirls are less than 0.2 inch (Condition 1). This is significantly less than the 1.4 inch of settlement at this location as presented by S&W and WSDOT.

Back Calculated Moduli

Calculated settlements presented in Tables 2, 3 and 4 above are significantly smaller than those reported by S&W and WSDOT in Figure 1. Modulus values for the confined aquifer materials were back calculated for these reported settlements at each location for comparison to baseline values in the GBR. The back calculated moduli are tabulated in Table 5.

Table 6. Back Calculated Moduli for Reported Settlement (ksi)

Location	30 ft. Thick Aquifer	60 ft. Thick Aquifer
Shaft Location	17	33
Yesler Way and Alaskan Way	15	29
Cowgirls	11	22

These back calculated values consider the effect of settlement of overlying soils at the respective locations as presented in Tables 2, 3 and 4; and the settlement of underlying soils are neglected. Assuming these values are constrained moduli, they would have a consistency equivalent of dense sands or a loose glacial till based upon correlations by Bowles (1982). Table 6 summarizes equivalent shear moduli values using a Poisson Ratio of 0.35.

Table 7. Equivalent Shear Moduli from Back Calculated Moduli (ksi)

Location	30 ft. Thick Aquifer	60 ft. Thick Aquifer
Shaft Location	4	8
Yesler Way and Alaskan Way	3	7
Cowgirls	3	5

The values presented in Table 6 are considerably less than the value of 170 ksi that is defined in the GBR for ESU 5 materials. Furthermore, the shear moduli fall near or below the bottom of the range reported in the GBR for ESU 5. In addition, moduli typically increase with depth as overburden stresses increase implying that, as depth increases, the shear moduli should creep towards the higher range presented in the GBR for ESU 5.

If these values are representative of the actual materials within the confined aquifer, this would be a significant deviation from baseline values of 20 to 500 ksi summarized in the GBR. Much of the insitu testing data reviewed (SPT blowcounts, shear wave velocity measurements, and pressuremeter testing) and depositional environment would suggest these materials are stiffer than what is back calculated.

Independent Evaluation of Soil Stiffness and Resulting Settlements

An additional independent evaluation of settlements is made using shear wave velocity measurements within the confined aquifer at borehole locations in the vicinity of access shaft and other locations. These shear wave velocities range from about 1000 to 2000 fps (see TB104, TB216, TB320, TB321, and TB323 in Attachment A). Using an average value of 1500 fps, a corresponding maximum shear modulus of 63 ksi can be calculated using a unit weight of 130 pcf. Reducing this value by 15 percent to account for modulus reduction at strain levels likely to occur during settlement yields a value of 54 ksi.

Table 7 below presents settlement values at the reference locations using a constrained modulus of 234 ksi based on the reduced shear modulus of 54 ksi and Poisson Ratio of 0.35.

Table 8. Independent Evaluation Settlement Values (in.)

Location	S&W Reported Settlement	30 ft. Thick Aquifer	60 ft. Thick Aquifer
Shaft Location	1.4	0.19	0.29
Yesler and Alaskan Way	0.7	0.20	0.24
Cowgirls	1.4	0.16	0.22

The above settlement estimates consist of compression of the soils within the confined aquifer and measured settlement of soils overlying the aquifer as presented in Tables 2, 3, and 4. Any contribution of settlement from underlying soil is neglected, which is appropriate considering vertical stress conditions should be relatively unchanged due to dewatering efforts within the confined aquifer.

Review of Tables 2 through 7 indicates settlement due to dewatering should be on the order of 0.25 inch or less. These values are consistent with our previous settlement analyses that were dated November 25, 2014. This is over 5 times less than the values presented by S&W and WSDOT on Figure 1 and 2 at corresponding locations. In addition, the lateral deformation profile is inconsistent with the values presented by S&W and WSDOT where settlement decreases steeply to the north while staying relatively constant to the south and east of the shaft before decreasing steeply. Such large discrepancies would indicate that errors exist in settlements derived from survey data; other phenomena are inducing or contributing to settlements; or, ground conditions differ over what are assumed or defined in the GBR.

Review of Manual Survey and inSAR Data

Manual survey and inSAR data was reviewed to identify any discrepancies that could provide more insight on settlements that might be attributed to dewatering at the shaft.

Manual survey data was received from STP through a series of emails. Estimated settlements at survey points around and within the vicinity of the shaft were mostly relative to deep benchmarks (DBMs) established in August 2012. The estimated settlement at benchmark locations was consistent to that presented by S&W and WSDOT in Figure 1.

However, review of the survey data and DBM installation reports indicated a number of discrepancies that could introduce errors into the manual survey measurements as noted below:

1. DBMs were actually installed throughout August 2012, but baseline horizontal and vertical coordinates were completed on August 14, 2012. This implies that the surveys were done in advance of installing some of the DBMs and could introduce error in subsequent surveys if the vertical coordinate is incorrect. This would be especially concerning if the actual rod top was the reference in the baseline survey.
2. It appears that DBMs were routinely surveyed and compared to the baseline value quarterly or semi-annually for many of the DBMs prior to 2014. However, the DBMs may have only been surveyed once in mid 2014 with previous readings made in early 2014 and late 2013. Only DBM-1 and DBM-2 showed any signs of settlement with respect to prior surveys, but these two DBMs were mostly used as reference for survey loops around the tunnel and shaft. Settlement due to some other means prior to the start of dewatering would have only been observed if the frequency of the measurements was similar to or more frequent than those in 2013.
3. Both DBM-1 and DBM-2 are used as the reference for many surveys within the vicinity of the tunnel and shaft. Any movement of either of these monuments may have translated into settlements at other survey points within the survey loop. We note that DBM-1 is located within the street at the entrance to the football stadium and is subject to heavy traffic, so it is plausible this monument may have sustained some damage in 2014.

We have looked at the most recent raw and processed inSAR based vertical displacement measurements as documented in a report by Soldata (2014). The processed dataset was reviewed and settlements were calculated for the shaft location; Yesler Way and Alaskan Way intersection; Cowgirls location; and, at DBM-1 and DBM-2. Screenshots of vertical elevation data plots used to estimate settlement are supplied in Attachment D. Table 8 summarizes inSAR based settlement estimates occurring over the entire range of imagery (July 5 and December 7, 2014) and during dewatering at the shaft (October 4 and December 7). Table 8 also includes manual survey and calculated independent evaluation values of settlement at noted locations.

Table 9. Settlement from Manual Survey and inSAR (in.)

Location	Manual Survey	inSAR between July 5 and Dec. 7 2014	inSAR between Oct. 4 and Dec. 7, 2014	Independent Evaluation Values
Shaft Location	1.4	0.6	0.4	0.19 to 0.29
Yesler and Alaskan Way	0.7	0.2	0.1	0.20 to 0.24
Cowgirls	1.4	0.5	0.5	0.16 to 0.22
DBM-01	0.6	0.5	0.2	N/A
DBM-02	0.2	-0.2	-0.1	N/A

Review of Table 8 shows that settlement estimates over the dewatering period are much less than those derived from manual survey. Additionally, the inSAR based settlement estimates are in agreement with the independent evaluation values of settlements and our original estimates (~0.25 in.).

Also, it appears from review of the inSAR data that settlement may have been occurring in the project area well before the start of dewatering. This is somewhat confirmed by Soldata in their reduction of the inSAR data. The manual survey data could be further indication that settlement has been occurring in the region over the last year considering the time between recordings at and between DBM locations.

Figure 7 present's settlement contours based on processed inSAR data at select points east of the shaft between October 4 and December 7, 2014. The settlements shown in this figure are much less than those presented by S&W and WSDOT in Figure 1. Further review of Figure 7 indicates settlement in locations of estuarial and tidal fill areas that were infilled as part of development of Seattle and within an area that has recorded subsidence historically. Review of a time-series of slides indicates that there has been a trend of settlement in the fill areas prior to dewatering. The shape and location of the contours do not show an association between settlement and shaft dewatering. The greatest area of settlement is located south and east of the shaft location, and settlement at the shaft location is about the same as that calculated herein.

We note the precision of the inSAR data measurements is low in the last three frames in comparison to preceding frames. Since the last frame of data is on December 7, 2014, the settlement estimates during the dewatering period could change as new inSAR data is acquired and incorporated.

Conclusions and Remarks

We have made a detailed assessment of reported settlements due to dewatering activities associated with construction of the Access Shaft. Our findings indicate that settlements as presented by S&W and WSDOT and shown in Figures 1 and 2 are very high in comparison to the independent evaluation of settlements and those calculated from review of the inSAR data. Moreover, this information supports our initial estimates that settlement at the shaft due to dewatering should be on the order of 0.25 inch.

Alternatively, if the settlements presented by S&W and WSDOT and shown in Figures 1 and 2 are correct, then subsurface materials within the aquifer would be softer compared to the GBR baseline values. This is verified by using GBR baseline values and conservative assumptions to calculate settlements of less than 0.25 inch at the three sites where it is reported over an inch of settlement occurred, and corresponding back calculated estimates of moduli that are more than 10 times lower than baseline values. To further strengthen this finding, review of subsurface insitu testing data within the project vicinity indicates soil stiffness is lower than the baseline value for ESU 5.

The differences in reported settlements and those derived from review of inSAR data is partly due to error in referenced survey datums, calculations, and collection methods. The estimated settlements from inSAR data are more indicative of actual settlements that have occurred during the dewatering period since they match calculated values. However, changes in settlement estimates using inSAR data should be expected as additional imagery becomes available. In the interim, we recommend that manual survey data be reviewed in detail so that settlement estimates can be verified and refined as needed.

A trend in increasing settlement to the south and east is observed in review of the inSAR data (Figure 7). Settlements are likely larger in these areas because the subsurface is composed of softer materials that were placed within estuarial and tidal areas through the historical development of Seattle. These infilled areas are likely still consolidating under their own weight, but additional time and data would be needed to properly assess to causes of subsidence instead of solely attributing it to dewatering.

Attachments: Figures 1 through 7
Attachment A: Boring Logs
Attachment B: Subsurface Profile used in Seismic Analysis
Attachment C: Settlement Calculations
Attachment D: Screenshots from inSAR Measurements

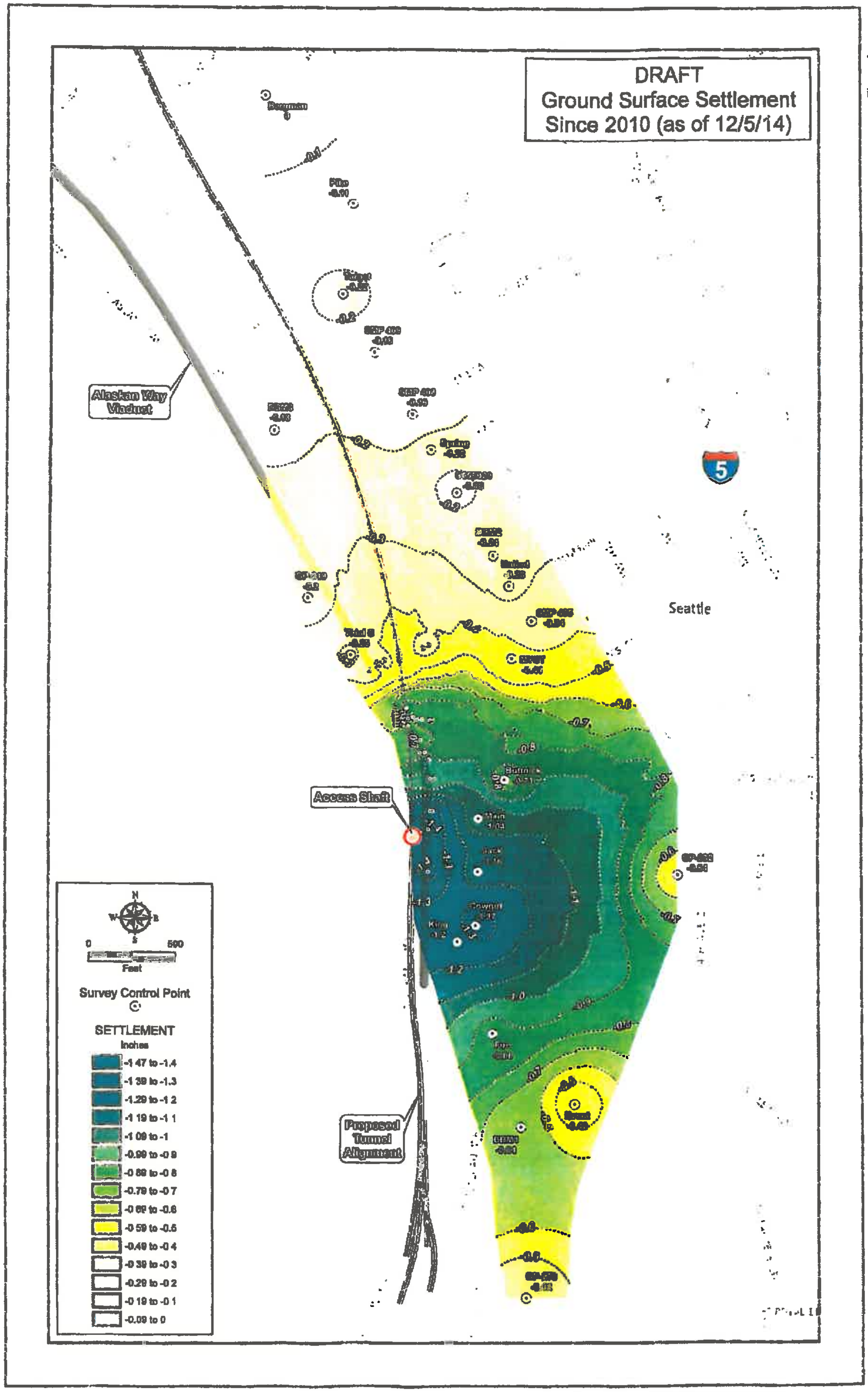

DRAFT
Ground Surface Settlement
Since 2010 (as of 12/5/14)
Alaskan Way Viaduct
Access Shaft
Proposed Tunnel Alignment
Seattle
5
N
W
E
S
0
500
Feet
Survey Control Point
SETTLEMENT
Inches
-1.47 to -1.4
-1.39 to -1.3
-1.29 to -1.2
-1.19 to -1.1
-1.09 to -1
-0.99 to -0.9
-0.89 to -0.8
-0.79 to -0.7
-0.69 to -0.6
-0.59 to -0.5
-0.49 to -0.4
-0.39 to -0.3
-0.29 to -0.2
-0.19 to -0.1
-0.09 to 0

Figure 1

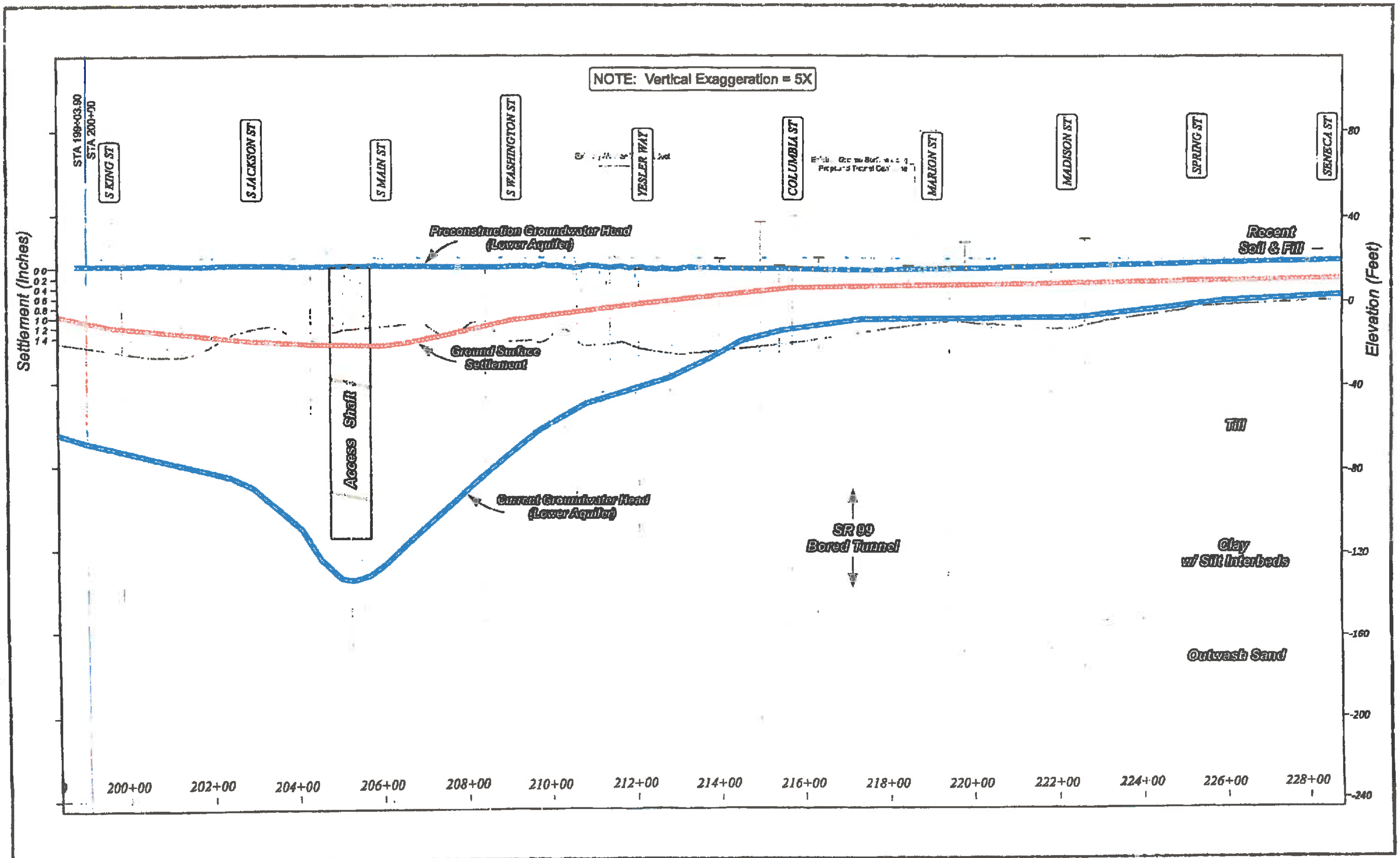

NOTE: Vertical Exaggeration = 5X
STA 199+03.90
STA 200+00
S KING ST
S JACKSON ST
S MAIN ST
S WASHINGTON ST
YESLER WAY
COLUMBIA ST
MARION ST
MADISON ST
SPRING ST
SENECA ST
Preconstruction Groundwater Head (Lower Aquifer)
Ground Surface Settlement
Current Groundwater Head (Lower Aquifer)
Access Shaft
SR 99 Bored Tunnel
Recent Soil & Fill
Till
Clay w/ Silt Interbeds
Outwash Sand
Settlement (Inches)
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
Elevation (Feet)
80
40
0
-40
-80
-120
-160
-200
-240
200+00
202+00
204+00
206+00
208+00
210+00
212+00
214+00
216+00
218+00
220+00
222+00
224+00
226+00
228+00

Figure 2

Alaskan Way Tunnel Project
Piezometer Readings within ~1000 ft of Access Shaft

Time graph

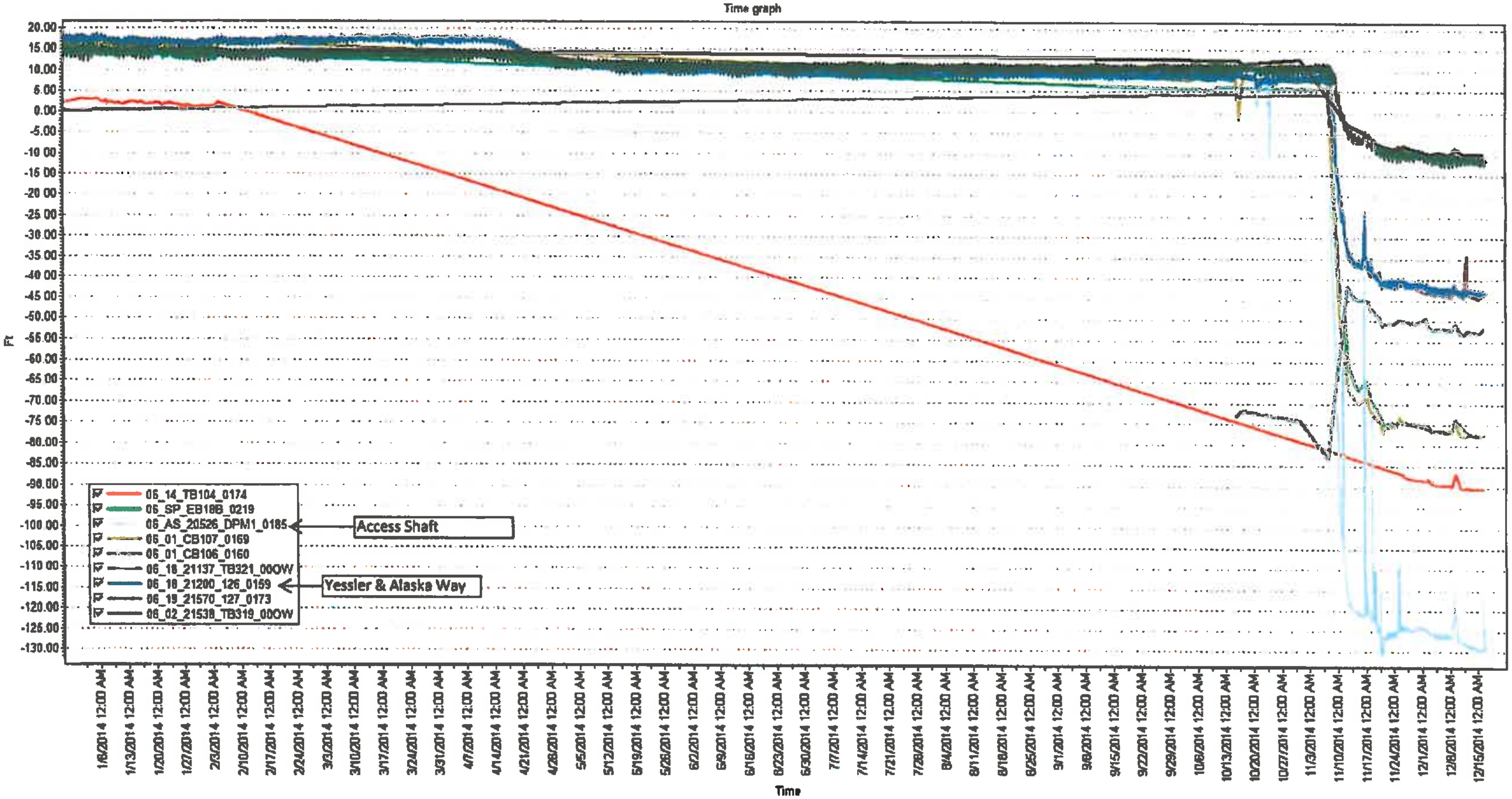


Figure 3 12/17/2014

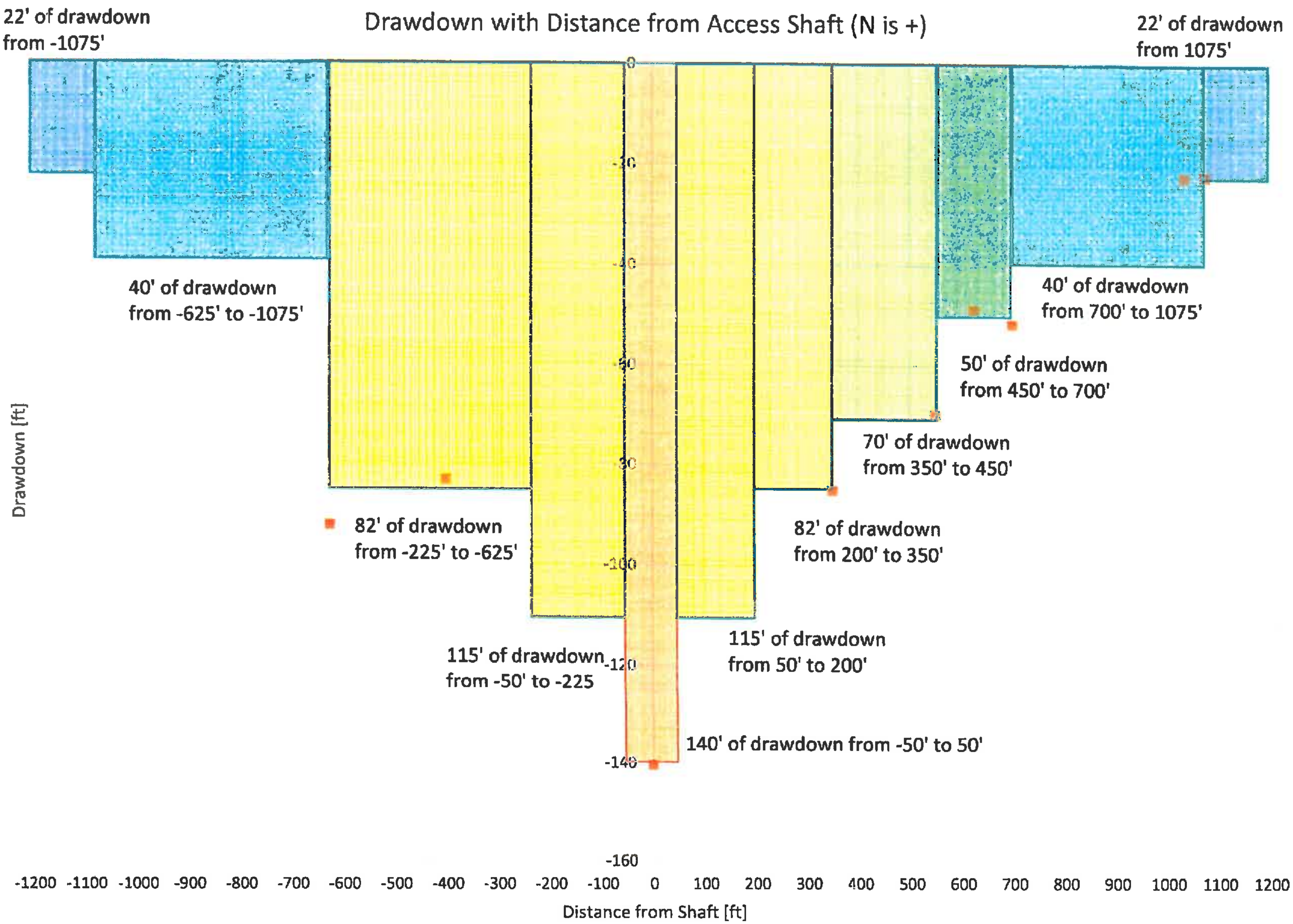
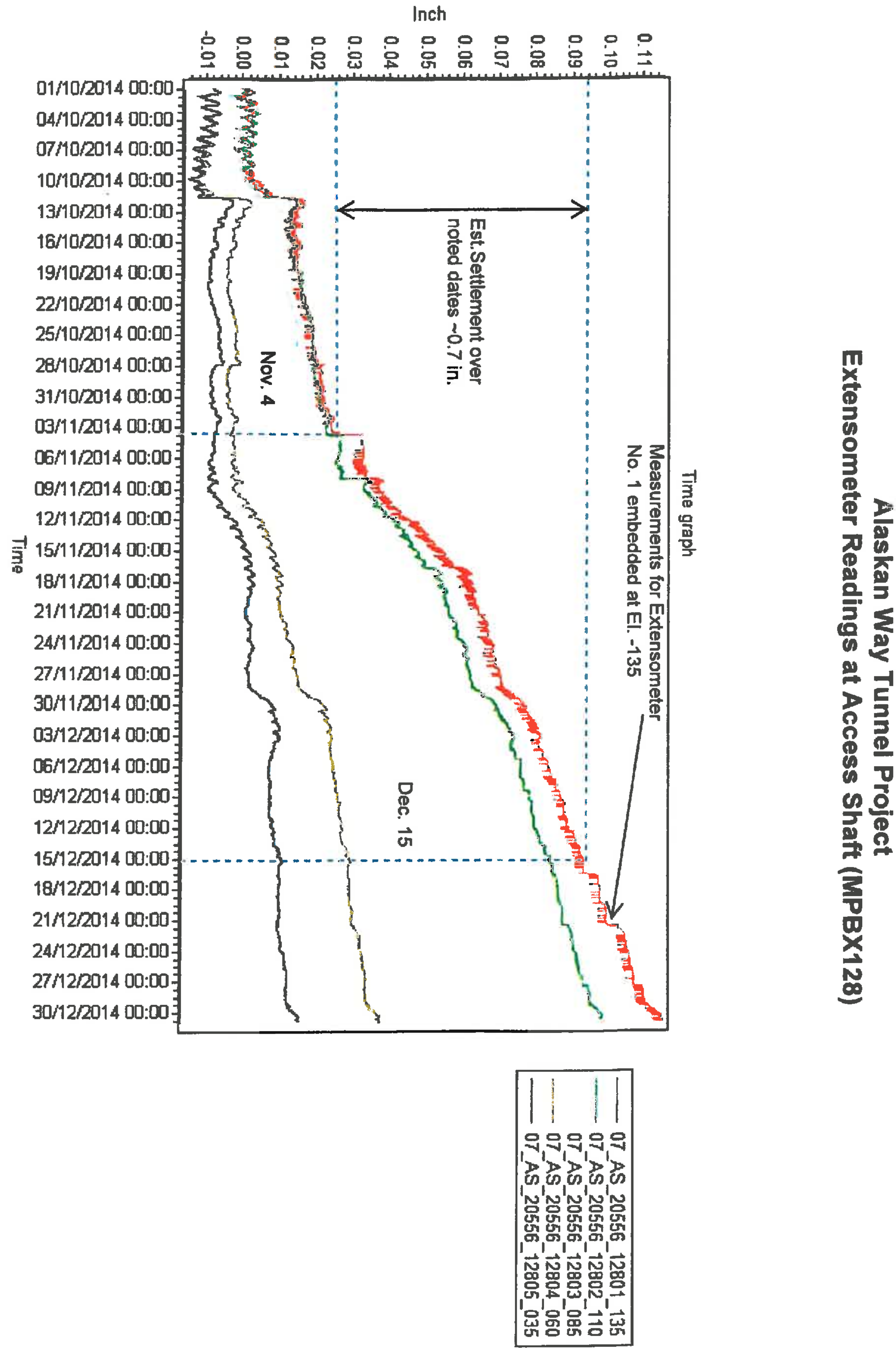

Drawdown with Distance from Access Shaft (N is +)
22' of drawdown from -1075'
40' of drawdown from -625' to -1075'
82' of drawdown from -225' to -625'
115' of drawdown from -50' to -225
140' of drawdown from -50' to 50'
115' of drawdown from 50' to 200'
82' of drawdown from 200' to 350'
70' of drawdown from 350' to 450'
50' of drawdown from 450' to 700'
40' of drawdown from 700' to 1075'
22' of drawdown from 1075'
Drawdown [ft]
Distance from Shaft [ft]
-160
-140
-120
-100
0
-1200 -1100 -1000 -900 -800 -700 -600 -500 -400 -300 -200 -100 0 100 200 300 400 500 600 700 800 900 1000 1100 1200

Figure 4


Alaskan Way Tunnel Project
Extensometer Readings at Access Shaft (MPBX128)
Time graph
Measurements for Extensometer No. 1 embedded at El. -135
Est. Settlement over noted dates ~0.7 in.
Nov. 4
Dec. 15
Inch
Time
07_AS_20556_12801_135
07_AS_20556_12802_110
07_AS_20556_12803_085
07_AS_20556_12804_060
07_AS_20556_12805_035

Alaskan Way Tunnel Project
Extensometer Readings at Yesler/Alaskan Way Intersection (MPBX126)

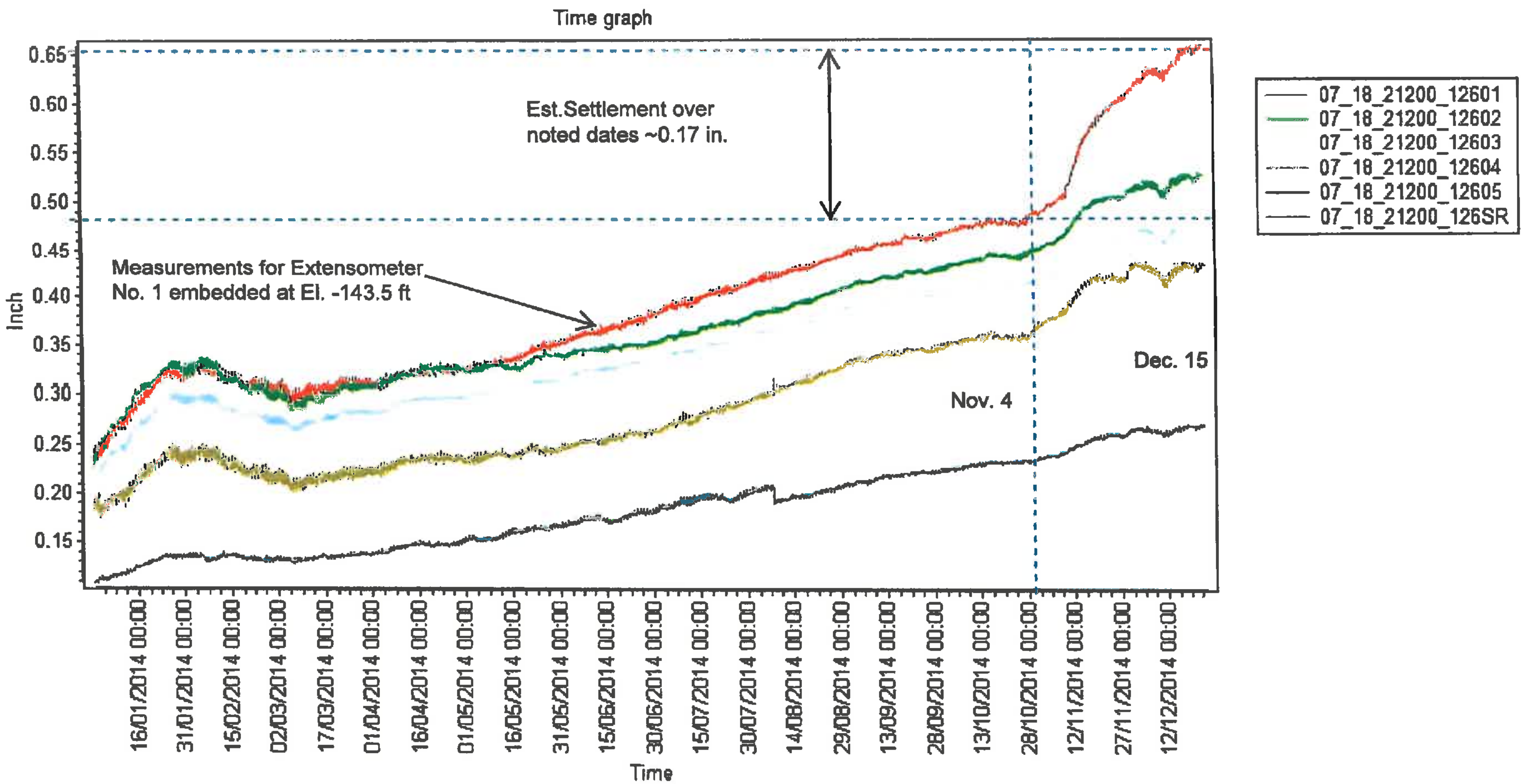
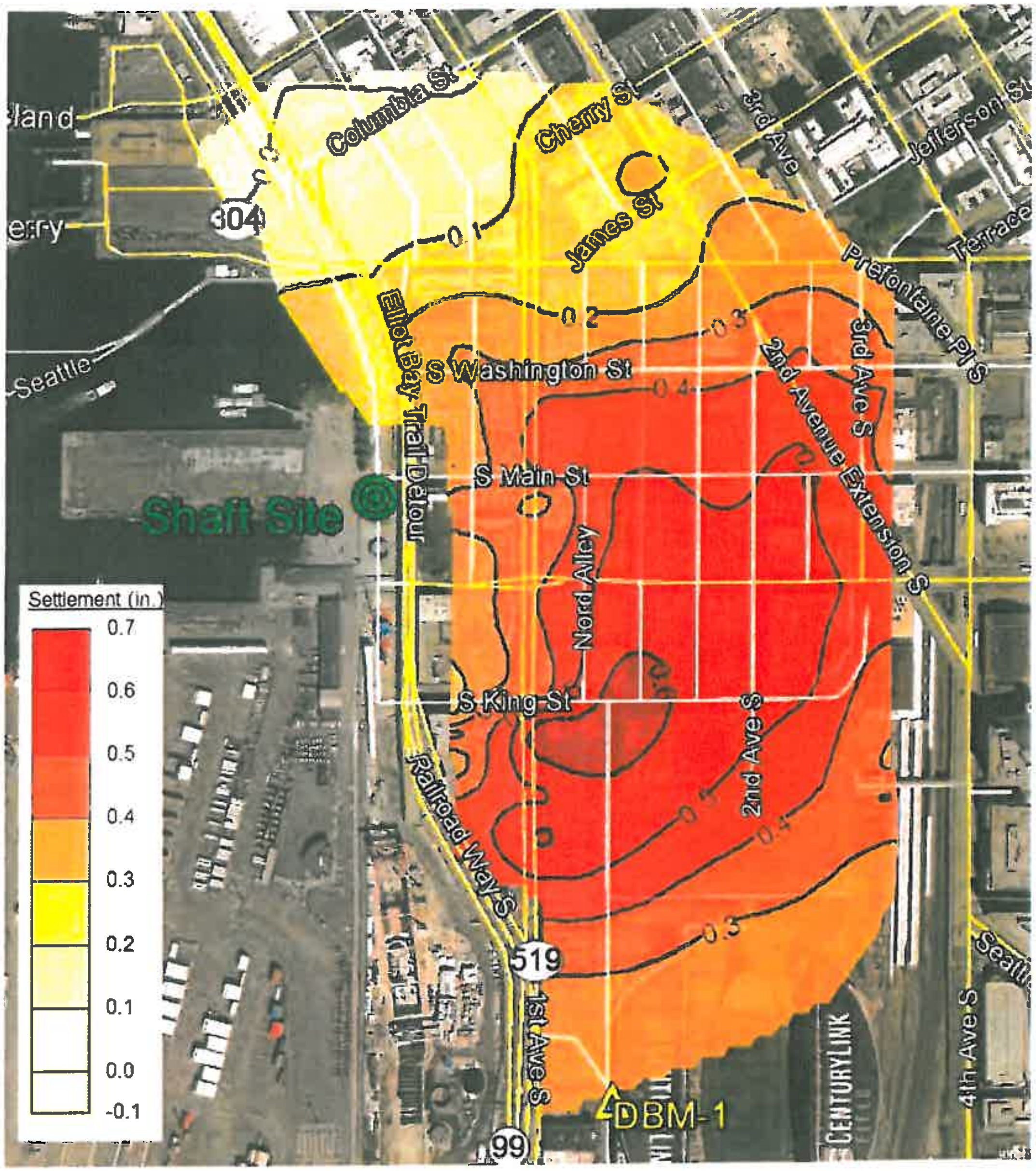


Figure 6 12/23/2014



Contours of Settlement Derived from processed inSAR data as reported by Soldata (Dec. 22, 2014)

BRIERLEY ASSOCIATES
Creating Space Underground

Appendix D: Brierley December 10, 2014 Technical Memorandum

BRIERLEY ASSOCIATES
Creating Space Underground

TECHNICAL MEMORANDUM

Date: December 10, 2014

To: Chris Dixon, Project Manager
Seattle Tunnel Partners

Cc: AJ McGinn, Brierley Associates

From: Phil Burgmeier. P.E., Brierley Associates
Patrick M. Smith, PhD, PE, GE, Brierley Associates
Jacob Mitchell, PE, Brierley Associates

Re: Ground Settlement
SR99 TBM Access Shaft
Seattle, WA

This memorandum presents our interpretation of local ground settlement associated with dewatering activities at the SR99 Access Shaft site. We also list some likely sources of ground settlement that should be investigated as they may have contributed to the reported regional ground settlement.

Ground Settlement Adjacent to the SR99 Recovery Shaft

We evaluated settlement magnitude and timing for Alaska Way Viaduct (AWV) Bent movement based on ASMP data that was downloaded from Geoscope. We determined that the maximum settlement of the viaduct attributable to shaft dewatering is less than 0.20-in along both the eastern and western bents, as shown on Attachments A1 to A4. This movement began in early October following a pump test using interior shaft wells and periodic use of the bathtub wells. However, the majority of this settlement occurred over a 4-day period immediately following activation of the bathtub wells and deep dewatering wells adjacent to the Access Shaft. The ASMP data shows negligible differential ground deformation after November 12th.

The viaduct settlement observed at the ASMP settlement monitoring points agrees well with the values presented in Brierley's November 25, 2014 viaduct settlement calculations. Those values ranged from 0.10-in to 0.25-in based on piezometer readings taken directly from Geoscope and the unloading/re-loading moduli values taken from the project GBR. Our November 25th viaduct settlement calculations are provided as Attachments A5 and A6.

It has been reported that dewatering for the TBM intervention last December, just south of the current TBM position, resulted in approximately 0.25-in of settlement, and that this settlement was recovered immediately afterwards when the wells were shut off. At the Access Shaft, pumping of the deep wells was interrupted for about 12 hours on November 16th, which correlates well with the settlement data, as a spike in ASMP readings (Attachment A1) appears on that day. This observed rebound from the intervention work and from the November 16th event strongly supports our calculations and assumptions, i.e., that the heavily over-consolidated soils underlying the shaft site will experience negligible settlement and that these soils will rebound following cessation of dewatering.

The location of the ASMP benchmark is not known to Brierley. It may be located on shifting, local ground, or it may be located on stable, remote ground.

Piezometer data from DBM-1 indicates that drawdown immediately west of the shaft is approximately 135-ft of total head in the underlying aquifer. Piezometer data from CB-107, located roughly 350-ft north of the shaft, indicates a drawdown of approximately 90-ft of total head in the underlying aquifer. EB-18B, roughly 400-ft south of the shaft, indicates a drawdown of approximately 90-ft of total head in the underlying aquifer. CB-106 piezometers, located roughly 550-ft north of the shaft, indicates a drawdown of approximately 65-ft of total head in the underlying aquifer. TB-104 piezometers, located roughly 625-ft southeast of the shaft, indicates a drawdown of approximately 80-ft of total head in the underlying aquifer. TB-321 piezometers, located roughly 625-ft north of the shaft, indicates a drawdown of roughly 60-ft of total head in the underlying aquifer.

The groundwater levels measured in the surrounding area demonstrate that the drawdown one block away from the shaft is one quarter less than measured at the Access Shaft, and the groundwater drawdown at a distance of roughly two blocks away is less than half of that measured at the shaft. As shown on attachments A8 and A9, the ground settlement associated with shaft dewatering is at most 0.11-inches at a distance of 200-ft from the shaft centerline based on the ASMP instrumentation. Thus, the measured decrease in settlement with distance from the shaft agrees well with the observed piezometer readings. These two observations, decreased drawdown and settlement with distance from the shaft, makes sense and are consistent with geo-hydraulic and geotechnical theory.

The shape of the drawdown curve is convex (i.e., the magnitude of the drawdown decreases with distance asymptotically). Since settlement due to dewatering is a direct function of total head drawdown, the pattern, magnitude, timing, and extent of the widespread ground settlement that has been reported by others for downtown Seattle cannot be linked reasonably or solely to a modest (less than 800 gallons per minute) dewatering operation at the Access Shaft. Based on a hypothetical assumption of a flat, horizontal groundwater drawdown line radiating from the shaft center, the dewatering operation could only be responsible for up to 0.25-in of settlement throughout the area.

Maintaining the assumption of a flat drawdown line, and back-calculating soil modulus values, we estimate that the 1.2 to 1.4-in of settlement that has been reported to the media for the downtown area could only be possible if the Young's Modulus of the ESU 5 layer (underlying sand aquifer) were only a fraction (4% to 6%) of the baselined unload-reload modulus values. However, this amount of discrepancy with the GBR values implies a vastly different geology than has been baselined for this project.

It is, therefore, Brierley's opinion that the piezometer data does not support the conclusion that dewatering of the underlying aquifer is responsible for the regional settlement that has been reported. We understand that WSDOT and its consultants are in the process of obtaining additional groundwater data in a larger area and we look forward to reviewing their analysis and conclusions as to the root cause of the reported regional settlement.

Brierley has requested, but has not received, a complete survey data set from STP including WSDOT's and City of Seattle's survey data with timelines for the alleged settlement magnitude of 1.2 to 1.4-in maximum. A plot tracking deep benchmark (DBM) movement movement with time has been provided to Brierley by STP and is presented in Attachment A7. We question whether the referenced benchmarks are located on stable ground in a regional sense. Aside from the ASMP readings over the time period after September 23, 2014, we question the anomalies, data gaps, and/or apparent adjustments to field instrumentation that existed prior to shaft construction. Attachment A9 provides an example east of the shaft and south of Yesler Way.

Brierley would like to review the survey data and a timeline of AWV settlement near Yesler way, where over 6-in of settlement has reportedly occurred following the 2001 Nisqually Earthquake. Review of this data over this longer timeframe, if made available, could shed light on a larger and longer-term issue associated with ground deformation that is known to have occurred before work began at the Access Shaft.

Regional Ground Deformation

It has been suggested that regional ground deformation well beyond the shaft area is direct result of associated dewatering efforts. However, there exist other sources or factors that should be investigated before attributing all estimated ground deformation to dewatering at the Access Shaft including:

- Area Seismicity
- Surveying Activities
- Historical Ground Settlement
- Groundwater Withdrawal and Recharge

Area Seismicity. Since dewatering for the Access Shaft began in earnest on November 4, 2014, and the Episodic Tremor and Slip (ETS) event of 2014 began on roughly November 3, 2014, we suspect that vertical ground movement measured at and surrounding the SR99 construction site is a factor of both dewatering-induced settlement and ETS activity since both have occurred simultaneously over the last 5 weeks. Notably, over 6-inches of viaduct settlement occurred near Yesler Way, which is about 700-ft north of the Access Shaft, following the 2001 Nisqually earthquake. To our knowledge, this settlement has not been explained by WSDOT and nothing was found in our literature review for this technical memorandum.

Attachment B provides background information concerning ETS in the Pacific Northwest. This deformation mechanism was discovered in the early 2000's using arrays of sensitive monitoring equipment linked to a common datum on stable ground. In the Seattle area, the ETS event recurs roughly every 14 months and typically lasts for about four weeks. The 2014 ETS event began in the Seattle area on November 3rd.

The period of dewatering at the SR99 shaft (roughly November 4 to present) overlaps with the 2014 ETS event, the SR99 benchmark settlement issue, erratic survey measurements that were first noted on November 16th, and erratic instrumentation measurements at the SR99 site through the month of November. We suggest checking downtown benchmarks against known stable benchmarks that are referenced by the regional Geodetic Array to determine the magnitude and extent of any regional ground deformations, as described on Attachment B1.

More information concerning regional ETS activity can be obtained from the following sources:

- http://www.geodesy.org/data/bysite/
- http://pnsn.org/

Surveying Activities. As we understand, settlements are estimated from the results of horizontal survey measurements at a combination of temporary and permanent benchmarks. The settlements estimates are made from comparing the change in elevation of a number of benchmarks relative to an established benchmark located away from the construction area.

Upon review of the survey results, we note that many of the measurements appear to be made at temporary benchmarks located in urban areas with high traffic and easily accessible by the general public. Disturbance or damage to one or more of the benchmarks could greatly alter the results. Identifying any damaged benchmarks and removing the bias from settlement estimates is warranted in surveys.

Also, we note that permanent benchmarks installed and maintained by WSDOT and the City of Seattle are within the area of reported settlement. However, survey measurements at these locations have not been provided to Brierley and we are unsure how many (if any) of these benchmarks have been used in settlement estimates to date. It would be prudent to perform an estimate of ground settlement based only on permanent benchmark locations since they are well constructed, maintained and surveyed periodically, and have been in place since the start of construction. However, consideration between dates of surveys should be considered in estimating times and rates of settlements.

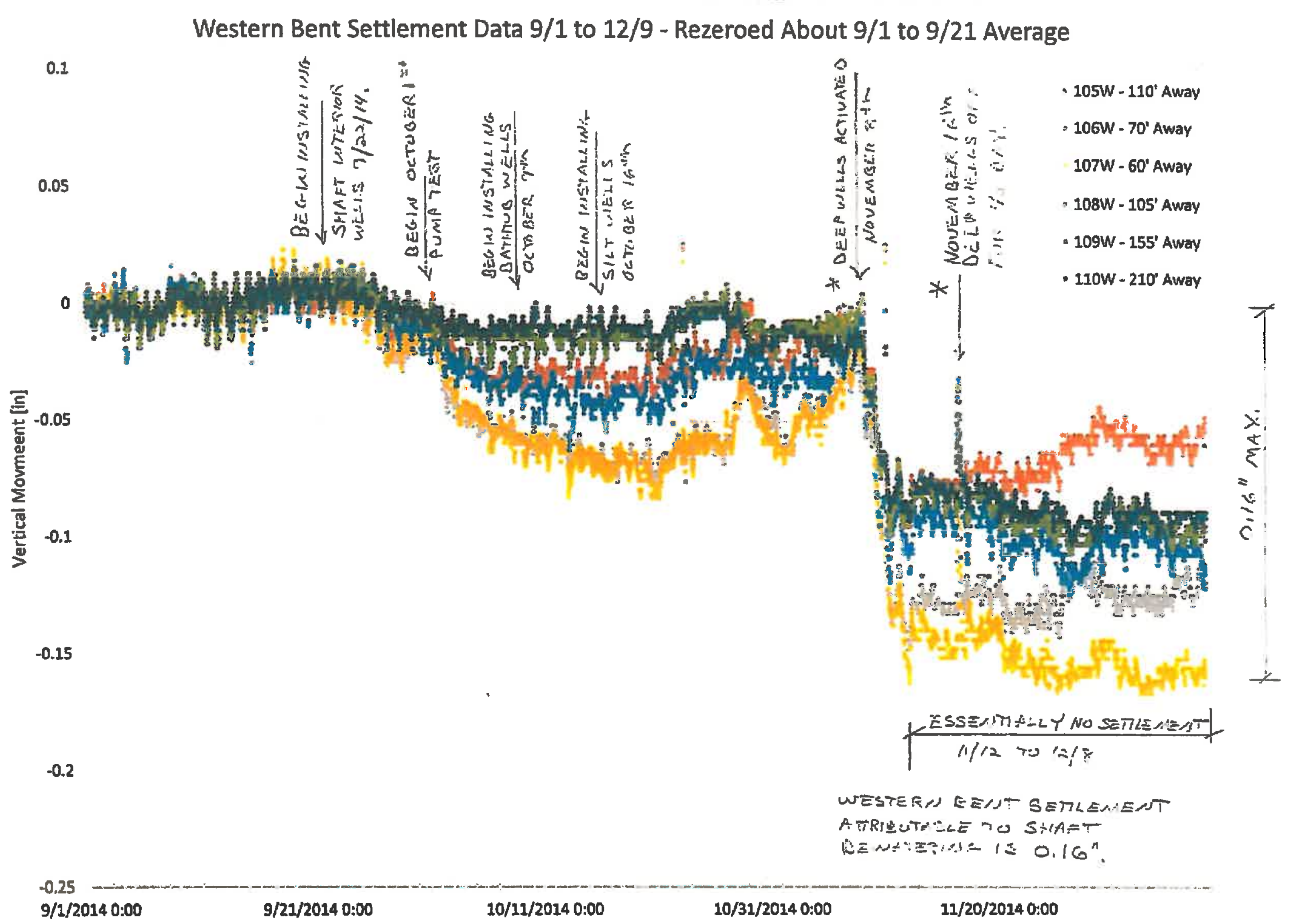
Furthermore, alternative survey methods could be used to estimate the amount and timing of any ground settlement throughout the region. These methods would likely include review of precision aerial/satellite imagery and radar measurements.

Historical Ground Settlement. Ground settlement has been observed consistently with time in the greater Seattle area. Notably at the Yesler Way area mentioned previously and also along Jackson Street, as noted by WSDOT's surveyors at the December 2, 2014 meeting. Details regarding these deformations have not been provided to Brierley at this time. We understand that satellite imagery provided to STP and WSDOT also supports the historic deformation of this region; and, in particular, the Pioneer Square area since the data began being gathered at the start of the SR99 Tunnel project. We understand that a report on this topic is forthcoming and we look forward to reviewing the findings.

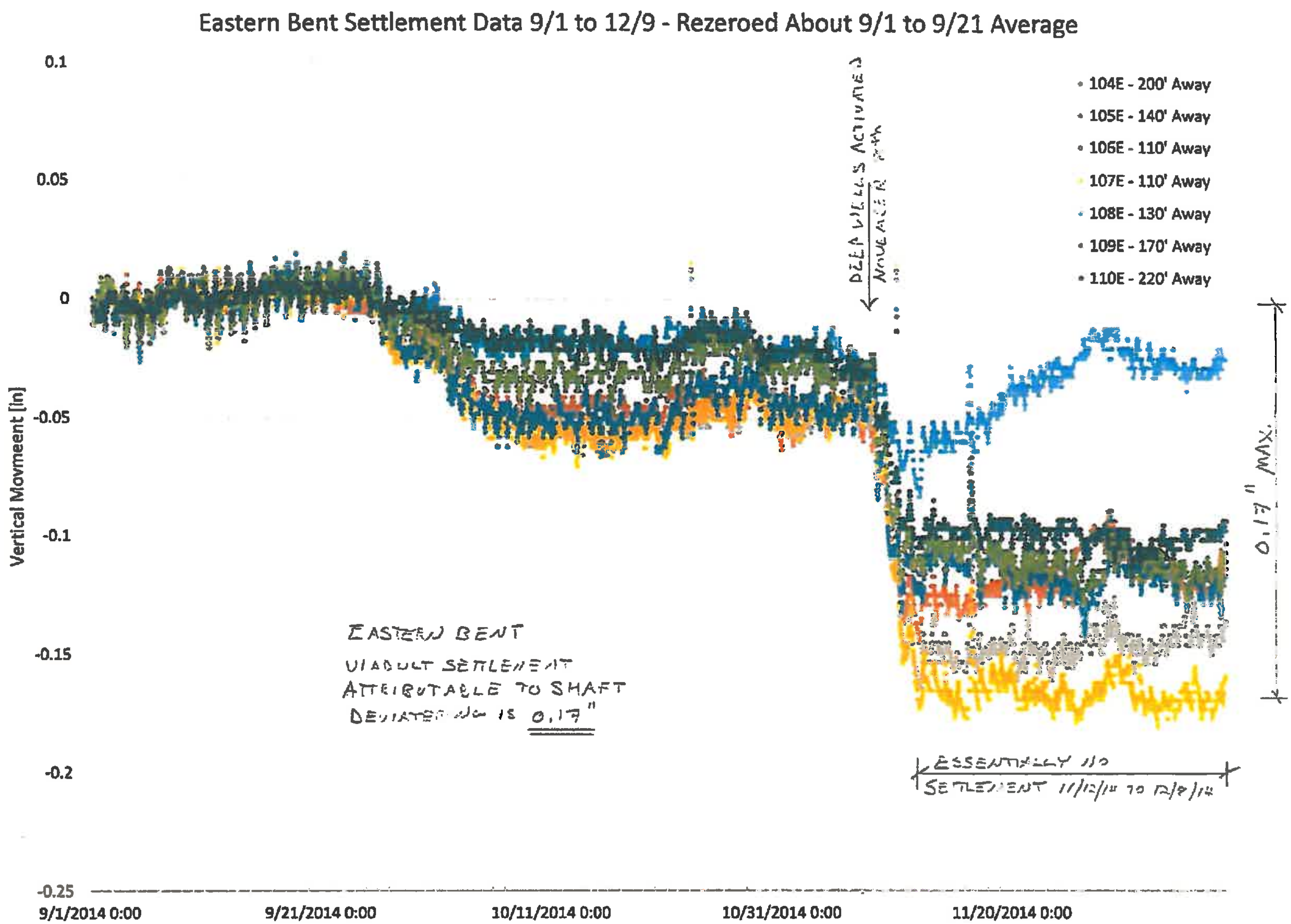
Please note, survey data from benchmarks installed and maintained by various municipalities and government agencies may be of use in making estimates of historical ground deformation since they provide past measurements of vertical elevation. As an example, Survey Control Data Sheets for the City of Seattle's benchmarks SNV-5133 and 3663-25D (Attachment C) indicate a decrease in vertical height from previous and most current measurements of around 0.4 inch. This information could be used to better assess historic and recent regional ground settlement.

Groundwater Withdrawal and Recharge. Numerous sources of groundwater withdrawal and recharge should be checked to see the effect on ground settlement in the area. Potential sources would include groundwater extraction wells, groundwater replenishment wells, injection wells to limit groundwater transport salts and toxins, other dewatering from construction activities in the local area other than those at the shaft site, etc. Times, rates, quantities and locations of withdrawal and recharge should be considered in estimates of regional ground settlement.

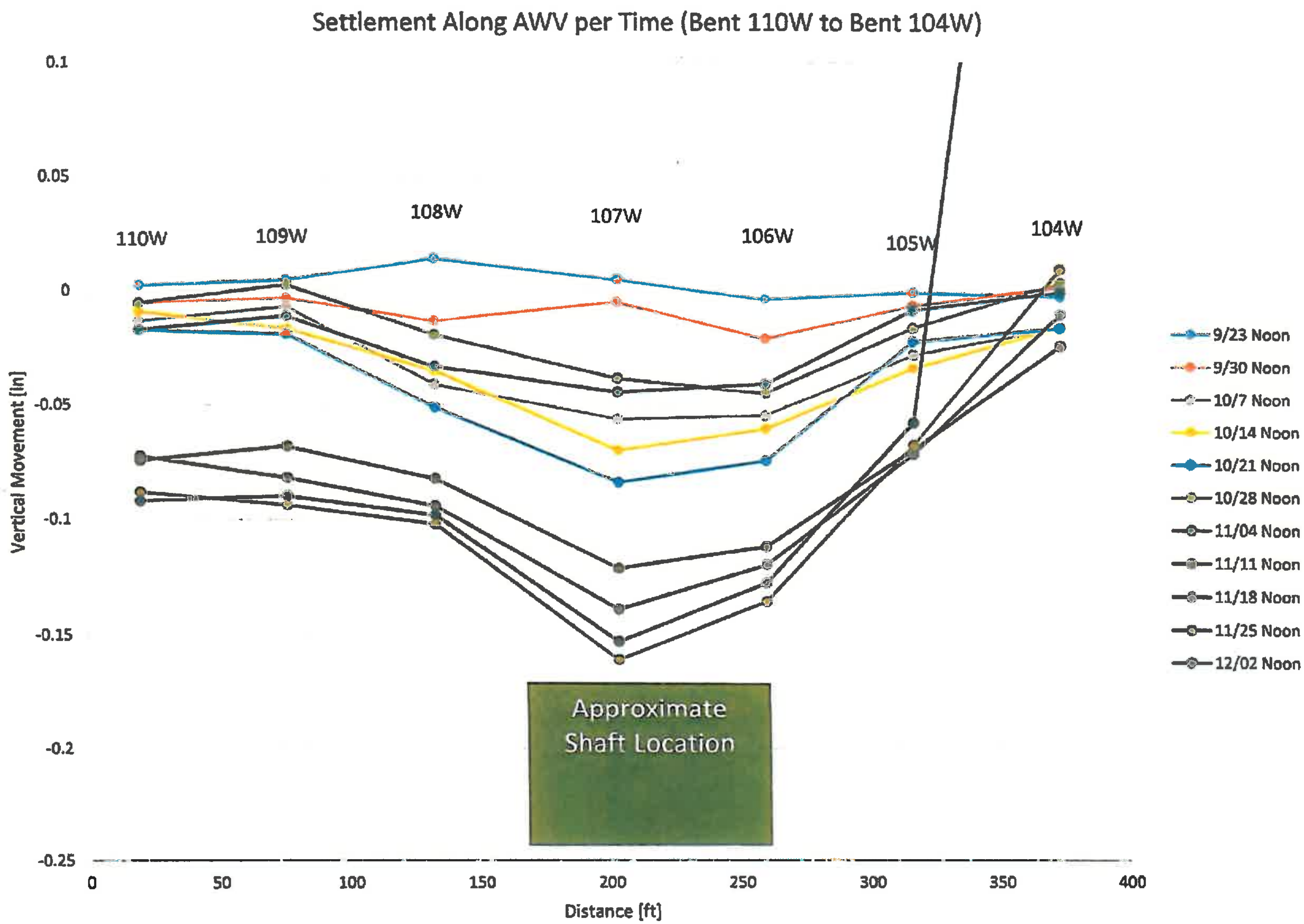
Attachments: Attachment A: ASMP Data Plots
Attachment B: ETS Background Information
Attachment C: Survey Control Data Sheets


Western Bent Settlement Data 9/1 to 12/9 - Rezeroed About 9/1 to 9/21 Average
Vertical Movmeent [in]
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
9/1/2014 0:00
9/21/2014 0:00
10/11/2014 0:00
10/31/2014 0:00
11/20/2014 0:00
105W - 110' Away
106W - 70' Away
107W - 60' Away
108W - 105' Away
109W - 155' Away
110W - 210' Away
BEGIN INSTALLING SHAFT INTERIOR WELLS 9/22/14.
BEGIN OCTOBER 1st PUMP TEST
BEGIN INSTALLING DATING WELLS OCTOBER 7th
BEGIN INSTALLING SILT WELLS OCTOBER 14th
* DEEP WELLS ACTIVATED NOVEMBER 4th
* NOVEMBER 12th
0.16" MAX.
ESSENTIALLY NO SETTLEMENT 11/12 TO 12/8
WESTERN BENT SETTLEMENT ATTRIBUTABLE TO SHAFT DEWATERING IS 0.16".

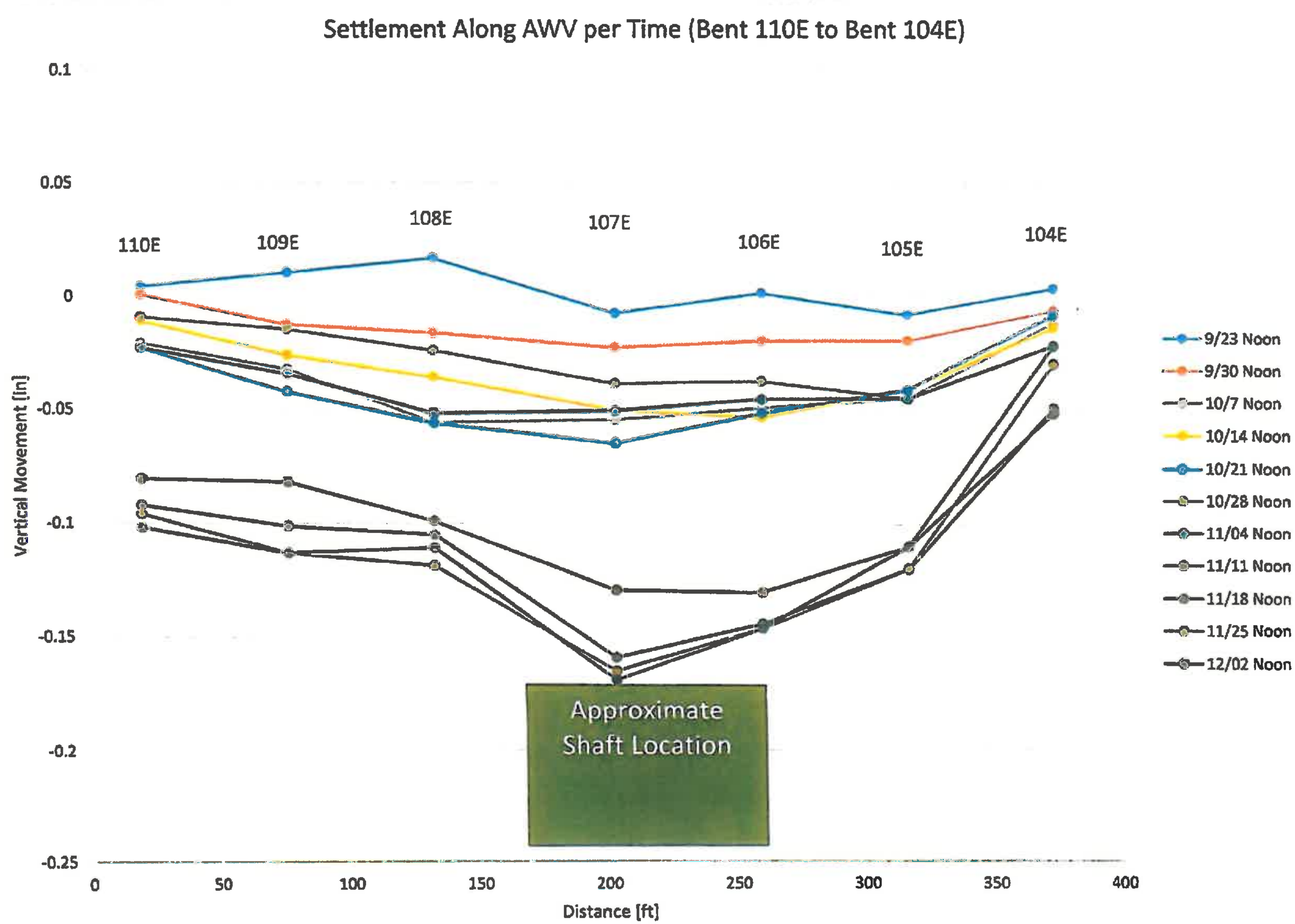
IV


Eastern Bent Settlement Data 9/1 to 12/9 - Rezeroed About 9/1 to 9/21 Average
Vertical Movmeent [in]
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
9/1/2014 0:00
9/21/2014 0:00
10/11/2014 0:00
10/31/2014 0:00
11/20/2014 0:00
104E - 200' Away
105E - 140' Away
106E - 110' Away
107E - 110' Away
108E - 130' Away
109E - 170' Away
110E - 220' Away
DEEP WELLS ACTIVATED
NOVEMBER 12th
0.17" MAX.
ESSENTIALLY NO
SETTLEMENT 11/12/14 TO 12/9/14
EASTERN BENT
VIADUCT SETTLEMENT
ATTRIBUTABLE TO SHAFT
DEWATERING IS 0.17"

A2


Settlement Along AWV per Time (Bent 110W to Bent 104W)
Vertical Movement [in]
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
110W
109W
108W
107W
106W
105W
104W
Approximate Shaft Location
0
50
100
150
200
250
300
350
400
Distance [ft]
9/23 Noon
9/30 Noon
10/7 Noon
10/14 Noon
10/21 Noon
10/28 Noon
11/04 Noon
11/11 Noon
11/18 Noon
11/25 Noon
12/02 Noon

A3


Settlement Along AWV per Time (Bent 110E to Bent 104E)
Vertical Movement [in]
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
-0.25
110E
109E
108E
107E
106E
105E
104E
Approximate
Shaft Location
0
50
100
150
200
250
300
350
400
Distance [ft]
9/23 Noon
9/30 Noon
10/7 Noon
10/14 Noon
10/21 Noon
10/28 Noon
11/04 Noon
11/11 Noon
11/18 Noon
11/25 Noon
12/02 Noon

A 9

A-5

BRIERLEY ASSOCIATES
Creating Space Underground

Job No. 114010-004 Date 11/25/14 Page 2 of 5
By KJM Checked GWP Rev
Client STP
Project SR 99 ACCESS SHAFT
Subject DEWATERING INDUCED SETTLEMENT

ESTIMATED SETTLEMENT h_p ON 11/24/14

PZ No.	h_{pi} (FT)	h_p (FT)	ΔH (PSF)	E (KSF)	t (FT)	ΔS (IN.)	S_{TOT} (IN.)	
PZ8-16	3	-4	437	864	20	0.12		
PZ8-64	-1	-19	1123	66096	30	0.01		
PZ8-89	2	-22	1498	66096	20	0.01		
PZ8-124	-11	-98	5429	20160	30	0.10	0.24	0.25"
PZ14-2	5	3	125	864	20	0.03		
PZ14-52	1	-19	1248	66096	30	0.01		
PZ14-84	-1	-36	2184	66096	20	0.01 0.10 (2)	0.15	0.2"
DPM1-119	-4	-85	5064	20160	35	0.10		
DPM1-134	6	-111	7301	25056	15	0.05		
DPM1-149	10	-125	8424	66096	50 (1)	0.08	0.23	0.25"
TB324-1	8	5	187	864	20	0.05		
TB324-44	-5	-15	624	66096	30	0.01		
TB324-79	-5	-15	624	66096	20	0.01	0.07	0.10"
UB103-49	0	-17	1061	66096	30	0.01		
UB103-84	0	-21	1310	66096	20	0.01	0.02	0.10"
CB107-10	5	3	125	864	20	0.03		
CB107-85	0	-17	1061	66096	20	0.01		
CB107-155	8	-75	5179	66096	50 (1)	0.05	0.09	0.10"

S < 0.25 IN. @ PZ8, PZ14, DPM1, TB324, UB103, & CB107 @ G.S.

(1) ESTIMATED THICKNESS
(2) ESTIMATED SETTLEMENT

ESTIMATED SETTLEMENT OF AWV S < 0.20 IN.

A6

BRIERLEY ASSOCIATES
Creating Space Underground

Job No. 114010-004 Date 11/25/14 Page 1 of 5
By AJM Checked GWP Rev
Client STP
Project SR 99 ACCESS SHAFT
Subject DEWATERING INDUCED SETTLEMENT

SOIL PROPERTIES

STRATA	S_{UR} (KSI)	S_{UR} (KSF)	ν	E (KSF)
ESU 1	NA	NA	0.3	864
ESU 4	220	31680	0.4	88704
ESU 5	170	24480	0.35	66096
ESU 6	50	7200	0.4	20160
ESU 7	60	8640	0.45	25056

$\Delta S_i = \frac{\Delta H (t)}{E}$

$S_{tot_i} = \sum \Delta S$

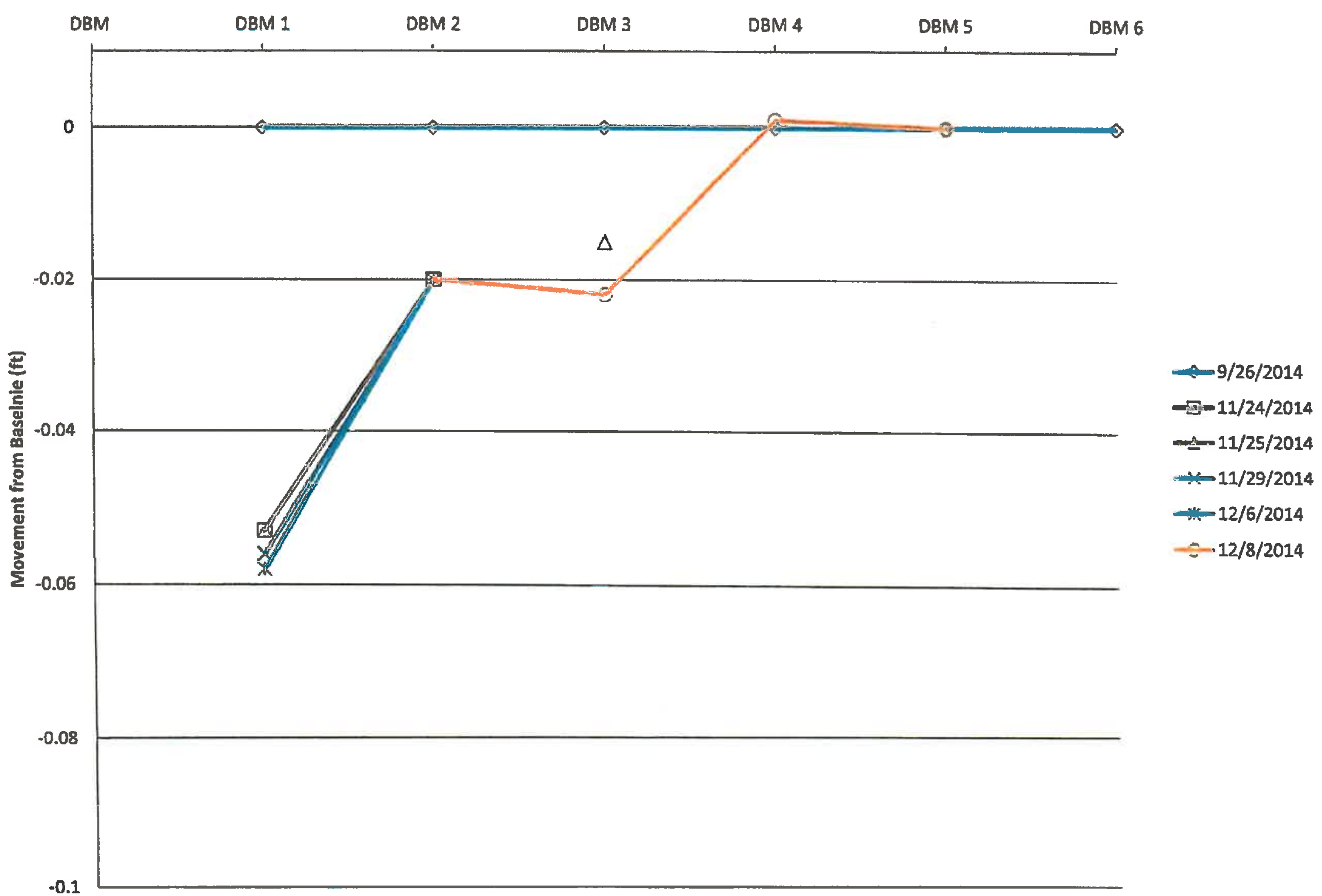
ESTIMATED SETTLEMENT h_P ON 11/24/14

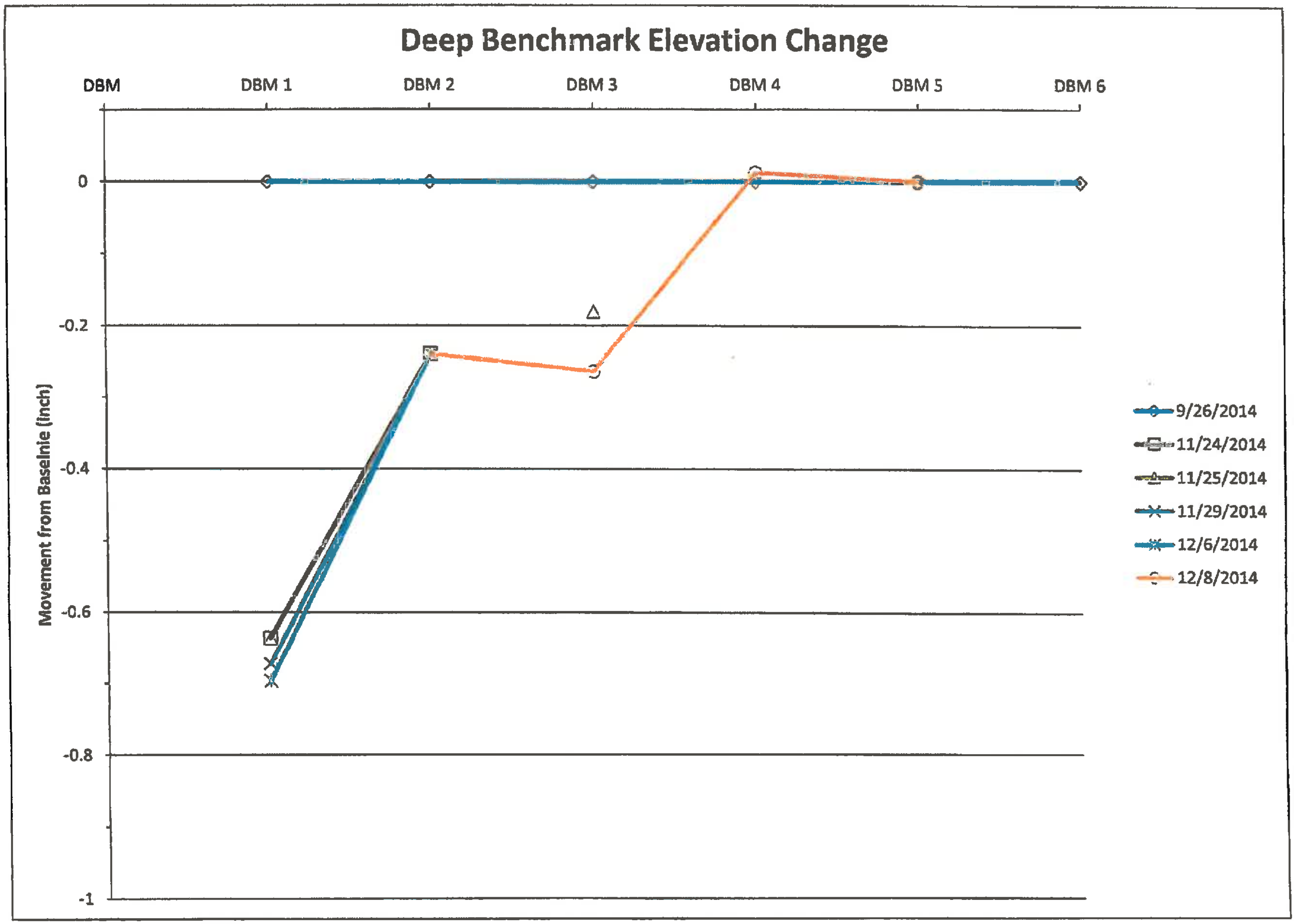
PZ No.	h_{P_i} (FT)	h_P (FT)	ΔH (PSF)	E (KSF)	t (FT)	ΔS_i (IN.)	S_{tot} (IN.)	
PZ5-9	7	4	187	864	20	0.05		
PZ5-54	-1	-41	2496	66096	30	0.01		
PZ5-86	-3	-48	2808	66096	20	0.01	.85	
PZ5-129	-20	-88	4243	20160	45	0.11	0.18	0.2"
PZ6-9	6	4	125	864	20	0.03		
PZ6-54	1	-18	1186	66096	30	0.01		
PZ6-84	2	-18	1248	66096	20	0.01		
PZ6-149	6	-132	8611	66096	50(1)	0.08	0.13	0.2"
PZ7-19	9	5	250	864	20	0.07		
PZ7-54	6	-40	2870	66096	30	0.02		
PZ7-87	4	-48	3245	66096	20	0.01		
PZ7-134	-6	-85	4930	20160	20	0.06	0.16	0.2"

S < 0.25 IN. @ PZ 5 PZ 6 & PZ 7 @ GROUND SURFACE

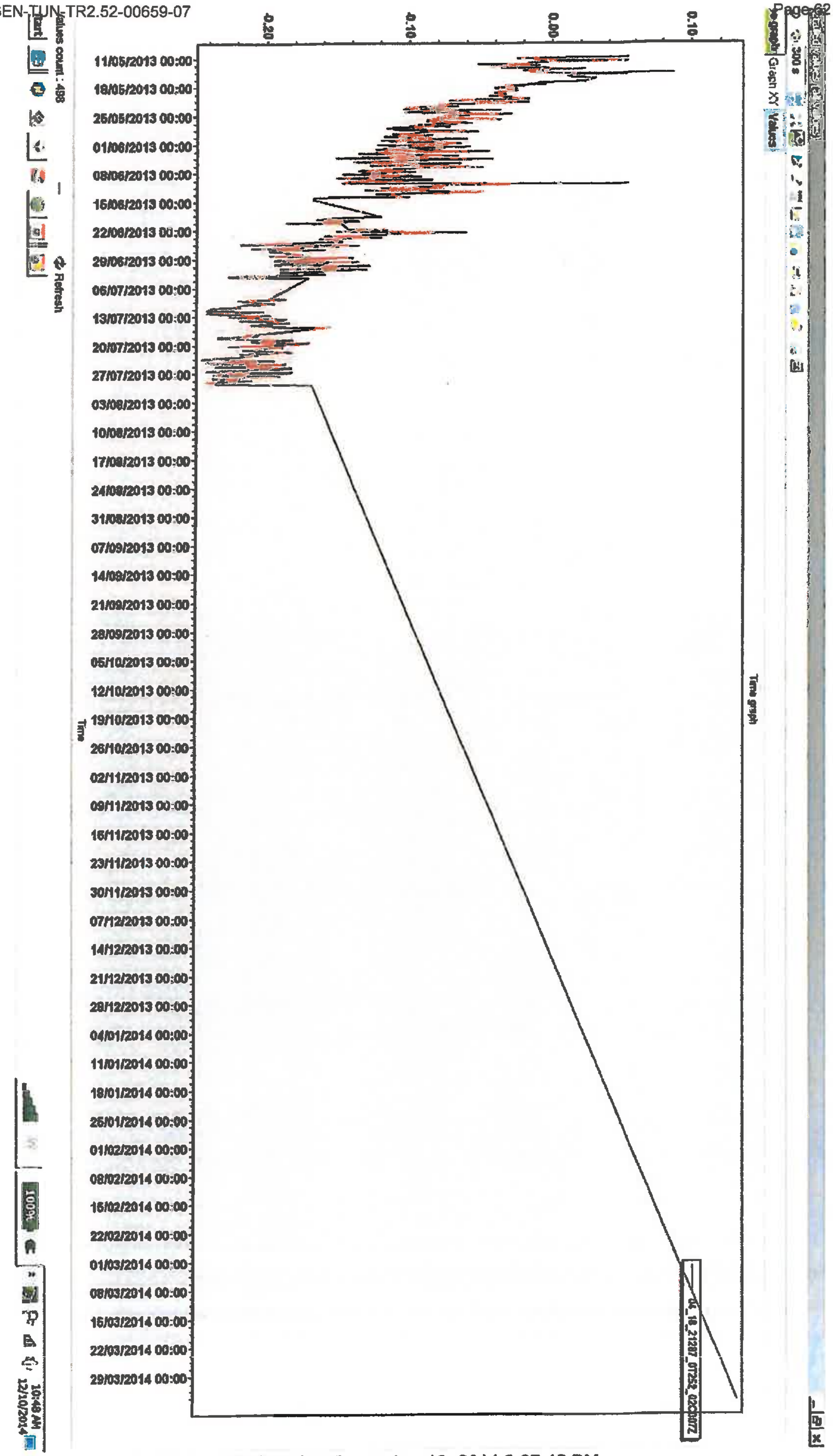
(1) ESTIMATED THICKNESS

Deep Benchmark Elevation Change




Deep Benchmark Elevation Change
DBM
DBM 1
DBM 2
DBM 3
DBM 4
DBM 5
DBM 6
0
-0.2
-0.4
-0.6
-0.8
-1
Movement from Baselnie (inch)
9/26/2014
11/24/2014
11/25/2014
11/29/2014
12/6/2014
12/8/2014

F2
AE


Values count : 498
Refresh
Graph XY
Values
Time graph
Time
-0.20
-0.10
0.00
0.10
11/05/2013 00:00
18/05/2013 00:00
25/05/2013 00:00
01/06/2013 00:00
08/06/2013 00:00
15/06/2013 00:00
22/06/2013 00:00
29/06/2013 00:00
06/07/2013 00:00
13/07/2013 00:00
20/07/2013 00:00
27/07/2013 00:00
03/08/2013 00:00
10/08/2013 00:00
17/08/2013 00:00
24/08/2013 00:00
31/08/2013 00:00
07/09/2013 00:00
14/09/2013 00:00
21/09/2013 00:00
28/09/2013 00:00
05/10/2013 00:00
12/10/2013 00:00
19/10/2013 00:00
26/10/2013 00:00
02/11/2013 00:00
09/11/2013 00:00
16/11/2013 00:00
23/11/2013 00:00
30/11/2013 00:00
07/12/2013 00:00
14/12/2013 00:00
21/12/2013 00:00
28/12/2013 00:00
04/01/2014 00:00
11/01/2014 00:00
18/01/2014 00:00
25/01/2014 00:00
01/02/2014 00:00
08/02/2014 00:00
15/02/2014 00:00
22/02/2014 00:00
01/03/2014 00:00
08/03/2014 00:00
15/03/2014 00:00
22/03/2014 00:00
29/03/2014 00:00
100%
10:48 AM
12/10/2014

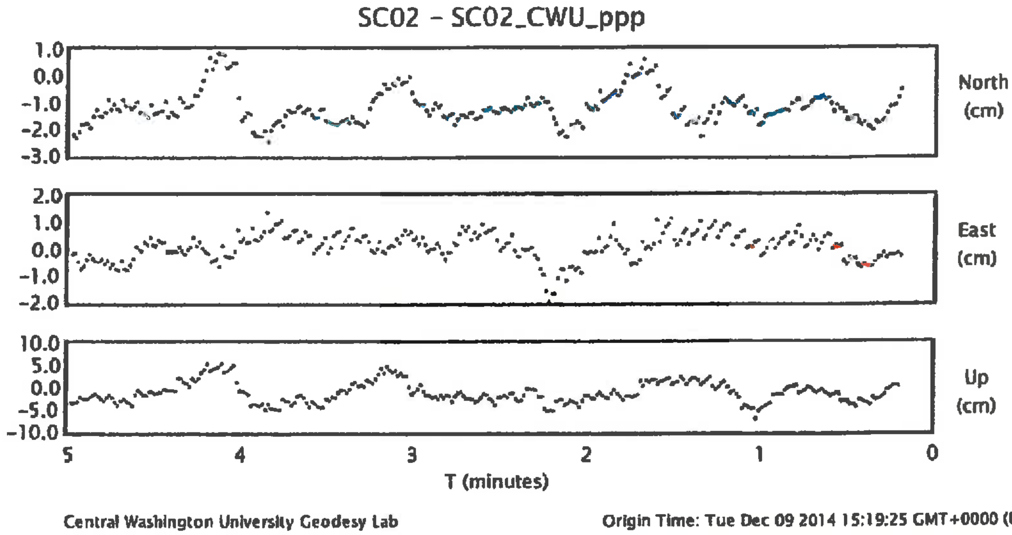
81

Pacific Northwest Geodetic Array
Central Washington University

GPS Data: By Site By Region Real-Time RINEX Tiltmeter: Data Sites

Real-Time Network in the Pacific Northwest

Alaskan Way Viaduct



Real-time plot of current GPS measurements on the Alaskan Way Viaduct in Seattle.

*Compatible with browsers employing modern industry standards for plotting maps and data streams such as: Safari, Google Chrome, Mozilla Firefox and Opera.

With existing seismic instruments, quarterly optical monitoring data, strain gauges, and accelerometers, the Alaskan Way Viaduct presents an optimal study for real-time monitoring. Not ony does this structure impact the people of Seattle, but the greater populace of Washington State as well.


GPS Looking North


Alaskan Way Viaduct


GPS Looking South

Real-time data provides corrections for local surveyors enabling instant measurement corrections. Time and money is saved since this eliminates the need for a site specific base station and the results are accurate to the millimeter.

82

Installing GPS Antenna

Data are stored at PANGA Lab in Ellensburg, WA -important since location is further from most major geologically hazardous areas of the Puget Sound area. These data are uploaded every second providing an instantaneous view of ground deformation leading to possible structure failures; allowing hazard assements and warnings to be accurately made.

Viaduct GPS

Installing GPS Antenna

Back

Central Washington University / Geology Department / 400 University Way, Ellensburg, WA 98926
Phone: (509) 963-2799 / Fax: (509) 963-1109

Pacific Northwest Geodetic Array
Central Washington University

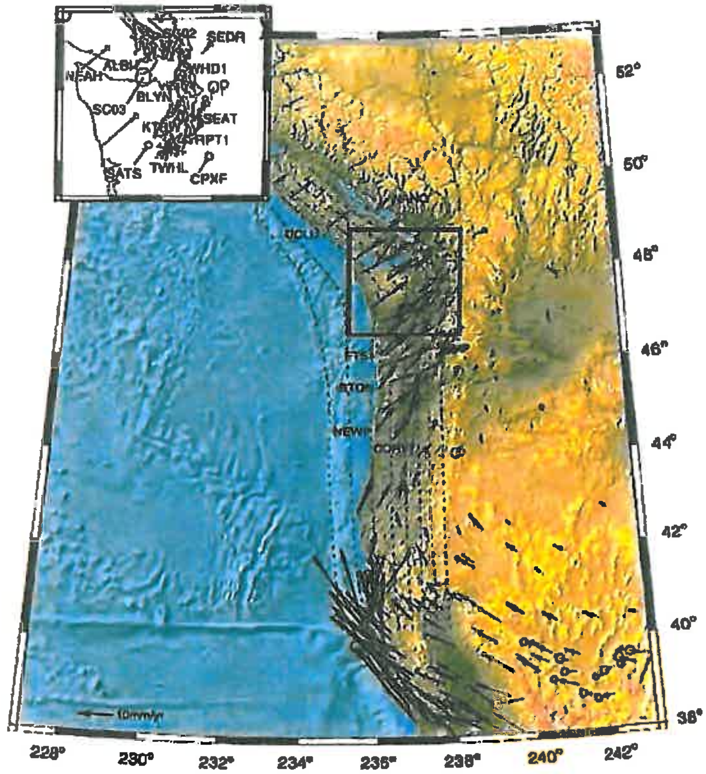
Slow Earthquakes, ETS, and Cascadia

In 2001, CWU researchers with the continuous GPS network Pacific Northwest Geodetic Array discovered periodic slow-slip across the Cascadia Subduction Zone. Previously undetected by seismic networks, these slip events exhibit regular recurrence intervals thus changing current understanding of earthquake behavior. Since this time, definitions for this newly discovered phenomenon have evolved. At first, the term "silent-earthquake" was employed to illustrate the absence of a seismic signature. Subsequent investigations and recent discoveries have led to a change in characterization. Now these slow-slip events are defined as eposodic tremor and slip (ETS).

In short, an ETS is a discreet time interval (episode) of relative tectonic plate movement (slip) coupled with high frequency seismic energy bursts (tremor). ETS usually last for around a few weeks duration as opposed to regular earthquakes where energy is released within seconds to minutes.

*graphic courtesy of Steve Malone

During an ETS relative plate motion occurs within a transition region of a subducting lithospheric plate. This transition delineates an area between the upper-locked and lower-slipping interface of a subduction zone. Stress between these two colliding plates builds since differential movement between the two zones is not entirely compensated from ETS displacement. Quick slip across the upper locked portion of a subduction zone occurs in large megathrust earthquakes when accumulated stresses surpass the upper region's locking threshold. In contrast, the subtle motion caused by ETS is so "slow" it's difficult to record at the surface. One might say "quiet" or possibly "silent" in nature, but definitely important since these events affect lithospheric plate interactions that are responsible for damaging "fast" earthquakes. Will the size of future large-scale megathrust earthquakes be reduced or will the time interval between these earthquakes increase with an ETS? A process with such imposing consequences is hardly "silent" in terms of relevance. In fact an ETS is not silent at all.



GPS Velocities

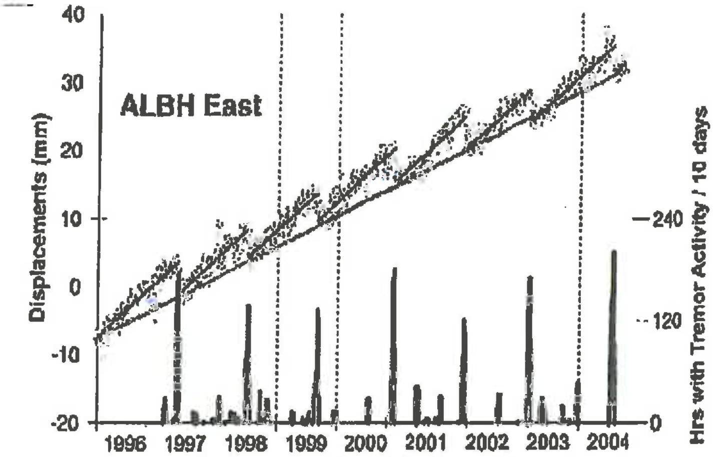
Why not silent?

Due to continuous plate motion, the daily solution of any GPS measurement is recorded as a velocity; reflecting the overall strain accumulating in the upper crust. During an ETS, GPS velocities change direction until the event passes. This minute signal would go unnoticed without extended timeseries. With the proper corrections and long-term stablizations, GPS allows accurate measurements for each day. Since ETS usually last for over 10 days, this provides a nice measurement of offset that could not be recorded on the longest period seismometer.

When slow earthquakes were first described by Dragert and others (2001) as well as Miller and others (2002), the motion of the Juan De Fuca and overriding North American plates was thought to occur in the absence of seismic energy. Since this time, Obara (2002) discovered seismic band energy that correlates with these slip signatures in Japan. This corresponding seismic energy is the tremor of an ETS. Typically between 1-6 vibrations per second, slow earthquake related tremor has since been detected in Cascadia as well. Although separating significant tremor from noise in a seismic dataset proves difficult, once an ETS is delineated by GPS, a clear trend becomes evident.

Tremor Counts with GPS Data

B5



*source: http://gsc.nrcan.gc.ca/geodyn/ets_e.php

How an ETS is measured:

Since we cannot measure offsets at depth directly, we infer motion on the fault surface with surface measurements. Before GPS, seismometers were the primary tool to measure earthquake type activity in the earth's crust. Besides the vague tremor associated with an ETS, the weeks-long motion of an ETS goes undetected by any seismometer. Today, with vast GPS arrays, we can now measure events at these time scales. In Cascadia, cumulative measurable surface offsets are less than 0.6cm (Szeliga et al., 2008); well within detectable range of GPS data over an extended time interval. While at the surface this deformation is easily resolved by GPS; unique source location of energy at depth is not.

GPS Satellites

GPS Receiver

Tremor allows better determination of source location. In both Japan and Cascadia, the depth of ETS tremor (and presumably slip) locates to 25-40km depth (Kao et al., 2005; McCausland et al., 2005; Obara, 2002), directly within the transition of a subduction zone. These independent tremor measurements substantiate arguments for a tectonic source and fine-tune the timescale of ETS activity. In the region of Washington state's Puget Sound, unlike a normal earthquake, a regular 14.5 month ETS periodicity has been proposed by Miller and others (2002) while a shorter period of 10.9 months seems to exist in northern California (Szeliga, 2004). In other subduction zones apart from Cascadia, ETS events exhibit no discernible periodicity although average horizontal offsets are comparable at around 5mm.

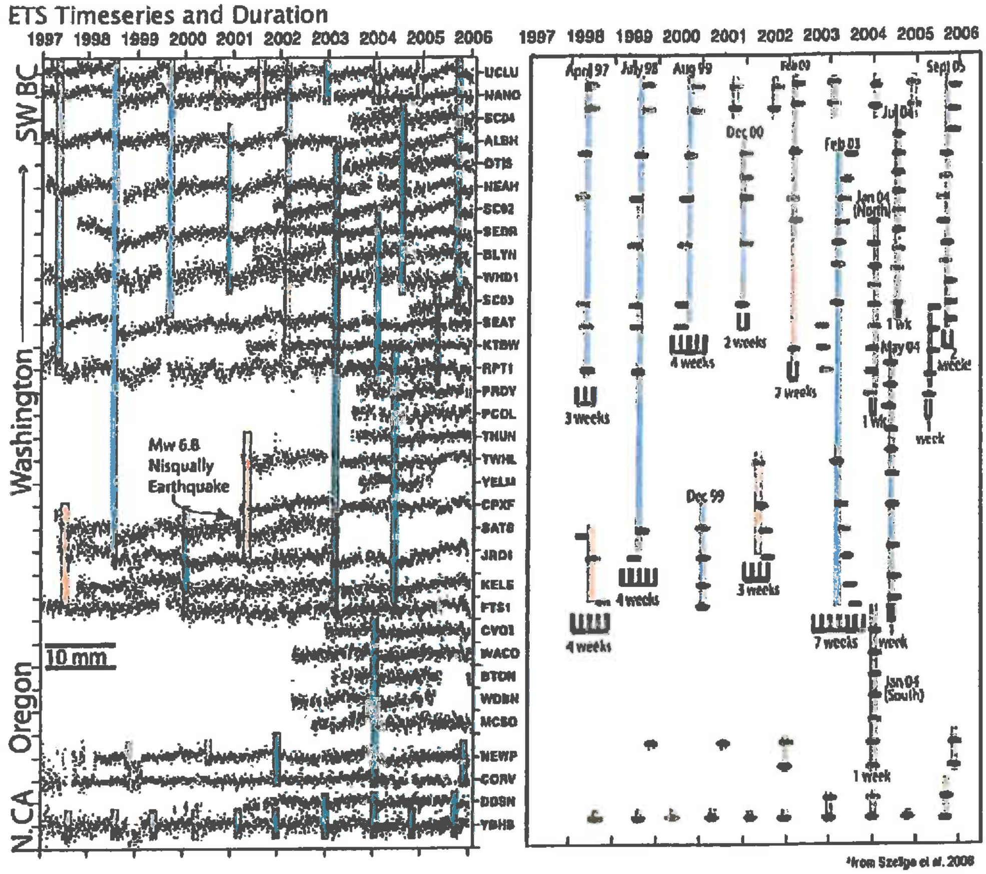
In general, vertical GPS uncertainties are large, and in Cascadia vertical ETS offsets are often small. Vertical offsets, therefore, require independent measurements since fault slip models are highly sensitive to this component. To address this issue, PANGA constructed a Very Long Baseline Tiltmeter Array (VLBT) in collaboration with UC Boulder. Not only does the Cascadia Tiltmeter Array resolve the vertical field to better than 1,000 times that of GPS, these tiltmeters also increase temporal precision with a sampling rate 100 times that of reliable GPS solutions; thus providing tighter constraints for fault models.

BC

- **Click here for latest VLBT monitoring of 2008 ETS**

Below are 9 years of GPS data from the Cascadia Subduction Zone along the convergent margin from northern California to southwest B.C., Canada. ETS events well recorded are delineated with blue lines and total slip-time is indicated on right plot by brackets. Most events last 3 to 4 weeks with amplitude between 2 and 7mm (Szeliga et al. 2008).

ETS Timeseries and Duration



Like any ordinary earthquake, an ETS has a measure of energy released during the event. This is calculated as moment magnitude (Mw). Cascadia ETS events average 6.7Mw (almost equivalent to the 2001 6.8Mw Nisqually Earthquake). This would represent around 2-3cm of slip across the plates at depth if measured ETS surface deformations are in fact caused by integrated slips at depth and tremor is simply the artifact of each individual slip of two portions of lithospheric plates in this subduction zone (Szeliga et al. 2008).

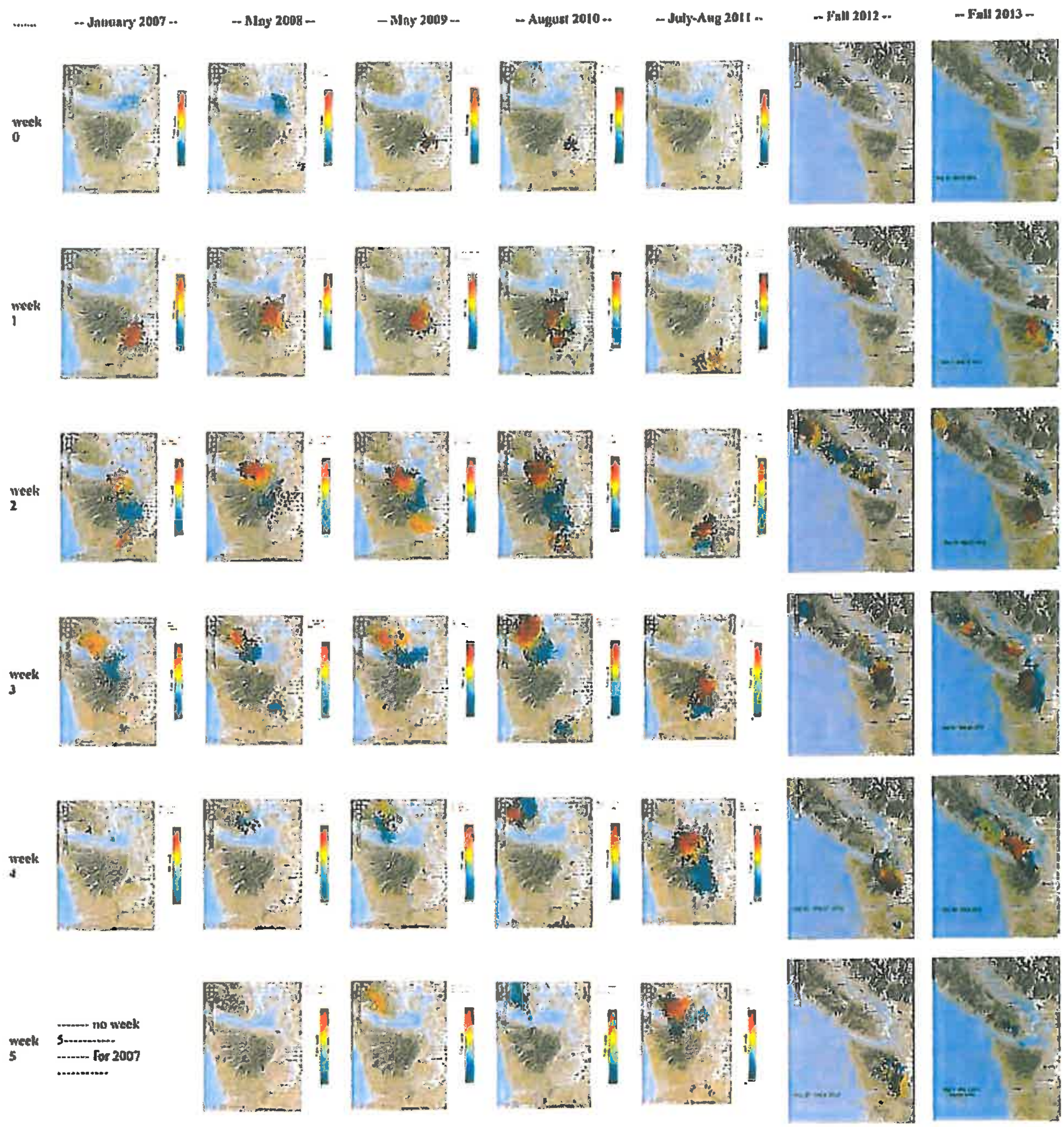
Segmented Fault Slip Model

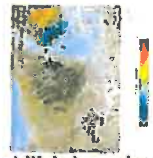
Tremor locations by week for last 5 ETS

Here are the tremor locations provided by the "wech-o-meter" for the past six ETS's in northern Washington - southern Vancouver Island broken out by week. The beginning of tremor (week 1) is defined as the first day that is followed by more or less continuous tremor spreading from the first day locations. "Week 0" is the week preceding this starting time. Each plot is for 8 days so the last day of one plot is the same as the first day of the next week's plot. Clicking on any plot provides a larger version of it. NOTE: In 2012 the area and scale of the plots changed because the tremor covered a MUCH larger area.

There is now a tremor density comparison for episodes since 2010.

2014 DATA NOT AVAIL



week 6	------- no week 6----------- ------- for 2007 -----------	------- no week 6----------- ------- for 2008 -----------		------- no week 6----------- ------- for 2010 -----------	 A Week plus one day - END	

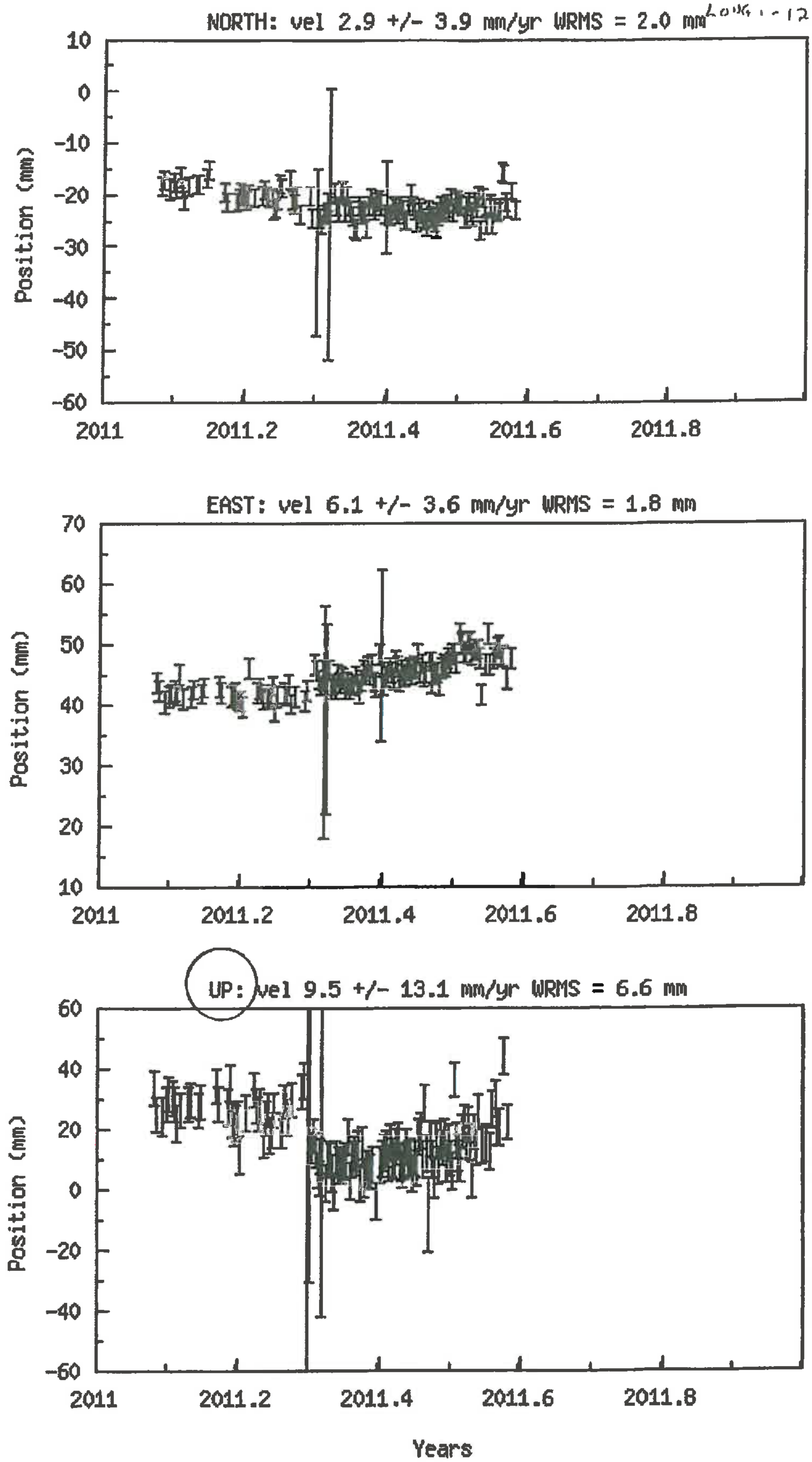
NOTE: Before 2010 the wech-o-meter did not have access to Canadian National Seismograph Stations and thus detections and locations during the latter parts of an ETS north of the Straits may be in considerable error.

B9

V096 - Raw Cent # 96

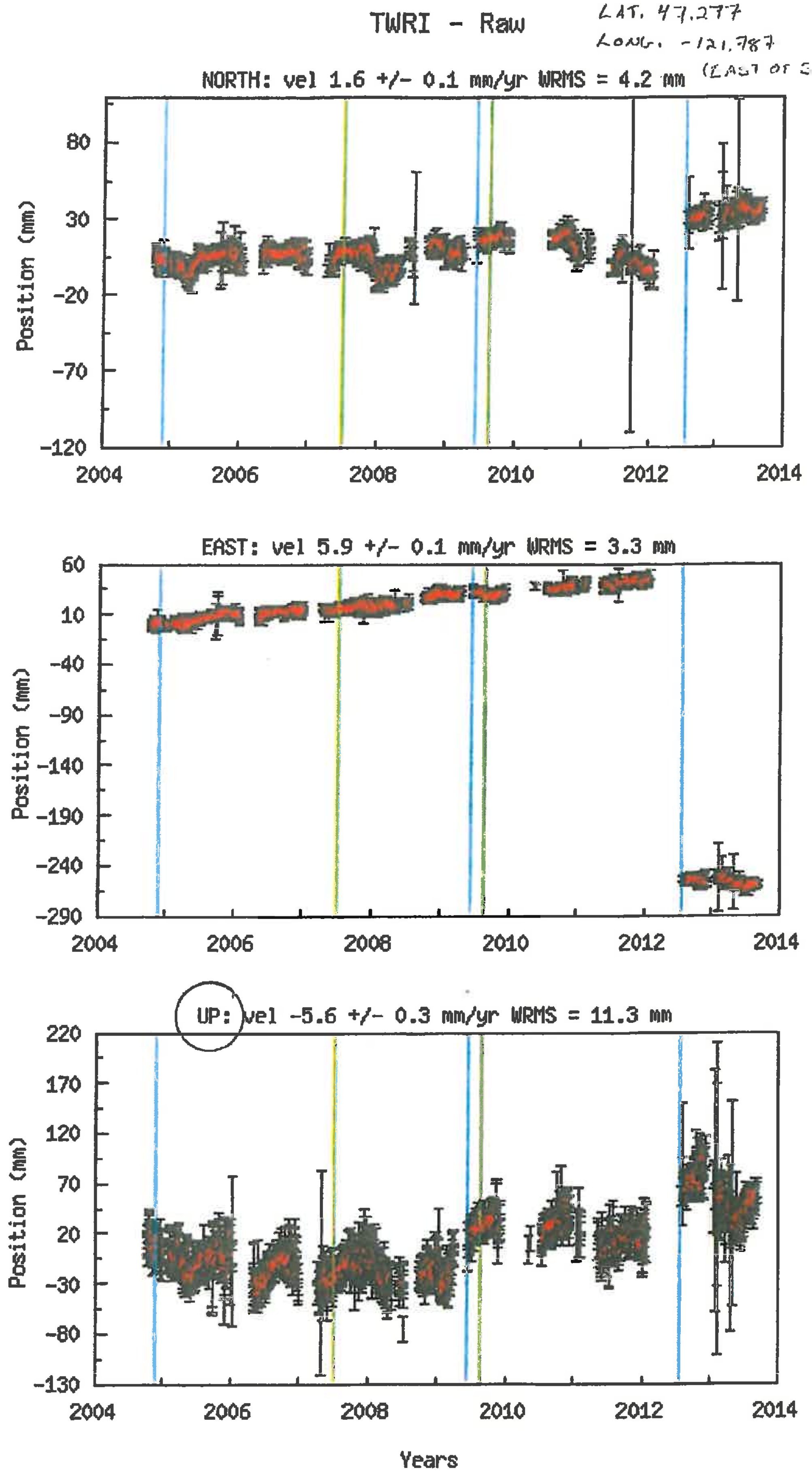
LAT. 47.602

LONG: -122.336



LAT. 47.277
LONG. -121.787
(EAST OF SHAFT)

B10



Ets Event Of Fall 2013

Shortcuts:
Main Tremor Index | Interactive Tremor Map | Realtime Tremor Map
ETS diagnostic Spectrograms (new ones comming soon) | Compare Maps |
PGC TAMS/SSA | Summary Spectrograms

Blog for ETS of Fall, 2013

Deep Tremor News: ETS event: Sep 7 - Oct 8, 2013 -

We were not expecting the next northern Washington - Southern Vancouver Island ETS until late Oct or Nov. 2013....... BUT, it may have started early. As of Sep 12, 2013 there have been 6 days of tremor activity in the area we have often seen an ETS start in the past; that is south-central Puget Sound. Thus we are again starting a blog here to document how this fall event goes.

Information will be posted on this page (latest at the top) and references to figures from time to time.

NEWS (latest at the top)

Oct 11,2013: I think it is time to call it over. The last day with any locatable tremor was Oct 8. So it went from Sep 7 - Oct 8, just over a month which is fairly typical for ETS events in this area. However, it was not as energetic has most previous events but extended over a larger area. We will need to wait untill the geodesy types figure out what the slip was for this event. I suspect it will not be as much slip at any individual place but may extend over a larger area.

Oct 7, 2013: Yep, it seems to be slowing down. Up until Oct 4 there was, at least moderate tremor over a good sized area in southern Vancouver Island. Then it got weaker and more dispersed and over the last two days just a few small batches anywhere in the region. So, is it over? Maybe, but this whole event has been strange. While it has lasted almost exactly a month the total number of tremor hours (654) and number of events (11,080) is only and 60% of the total for the last ETS that covered about the same region. Since this one has bounced around more than we have seen in the past, the geodesists say it is still low on the amount of slip and the total tremor is still not that much, maybe it will continue to bounce around and fill in. To help compare with previous ETS's I have filled in the comparative weekly tremor maps and the total ETS density maps for this episode. Check them out and do your own interpretation.

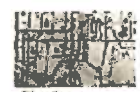
Oct 3, 2013: This time, I was only partially wrong. Maybe I am getting better at anticipating this silly thing. Indeed the two northern batches of tremor merged into one large batch, but they didn't then quit as I had previously predicted. Instead the southern batch seems to have died out. There is a hint that over the past couple of days the single batch that now extends from northwest of Port Alberni down to Victoria has shifted slightly up-dip and strengthened in the south while becoming weaker in the north. During this period there have been times with very strong tremor on south-central Vancouver Island stations. To this seismologists untrained eye it seems that some of the GPS station in the northern Olympics and Southern Vancouver Island are showing changes. Surely the GPS gurus should be able to confirm slip in this area, at least over the past week or so. So, what next? Anyones guess. It is not likely to move back south across the straits since that region has already had pretty strong tremor a week or so ago. It has already been farther north. Therefore, there is nothing for it to do but stay where it is and slowly die out

Or.... maybe not. I just got word from Herb Dragert that this ETS may not be quite over. *Over the past 9 days we have seen surface deformation at a number of sites. Of the GPS sites that are included in our network analyses, the largest horizontal offsets we see up to now are about 5 to 6 mm (at SC03 and P424). Our horizontal offsets at ALBH (Victoria GPS*


Recent EQ
Map


Seismo Blog
Posts


Earthquake
Search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Ets Event Of Fall 2013
ETS event of winter 2014
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Legacy Web Pages
Seahawks

PNSN > Tremor Research > ETS event of winter 2014

ETS event of winter 2014

Shortcuts:

Main Tremor Index | Interactive Tremor Map | Realtime Tremor Map
ETS diagnostic Spectrograms (blue boxes) | Compare Maps
PGC TAMS/SSA (requires special account) | PANGA geodesy plots

Blog for ETS of Winter 2014

Deep Tremor News: Nov, 2014 - .....

This BLOG-like page is being generated in a form similar to previous ETS ones to document and provide information on a Northern Washington ETS that should start this this winter. There are no special experiments in the field for this ETS. The only special seismic field experiement under way currently in the region is the Imaging Magma Under St. Helens (iMUSH) experiment. It will certainly record tremor associated with the coming ETS but is not well located to study it. We will be tracking and reporting on this ETS using data only from the real-time regional networks (UW, CN, TA, PB, CN) and/or information reported to us by others.

ETS dates: unknown

Information will be posted on this page (latest at the top) and references to figures from time to time.

NEWS (latest at the top)

Nov 18, 2014 - After a false alarm reported in a PNSN blog post back in early September there seemed to be no unusual tremor activity in the region untill recently. Starting on Nov 3, 2014 a persistent tremor sequence began in central Vancouver Island and progressed slowly southward. As of Nov. 14 the sequence had continued long enough to be considered a full ETS. Based on a request sent out to several ETS researchers for their opinion on this activity a PNSN blog was posted with some interesting analysis. Subsequent observations and comments will be posted to this special tremor page.


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Tweets

PNSN @PNSN1 3h
UPDATE: Mag:2.7, 40.3 km (25.0 mi) E - Morton, WA, Depth 5km, 2014/12/09 12:29:UTC V2 #uw.6042976 t.co/5tnh4d9

PNSN @PNSN1 17h
@JohnFMcBride1 The tremor in the PNW continues. PNSN

Compose new Tweet...

ESS UW USGS ANSS Blog Did you feel it? Donate

Region Options (?)

- All
- N. Vancouver Island
- Vancouver Island (more)
- ☑ Northern Washington
- Southern Washington
- Northern Oregon
- Central Oregon
- Southern Oregon
- Northern California
- N. Central California

Time Options

Start: 11/03/2014 End: 12/08/2014

Single Range

Type: Color vs. Time

Download

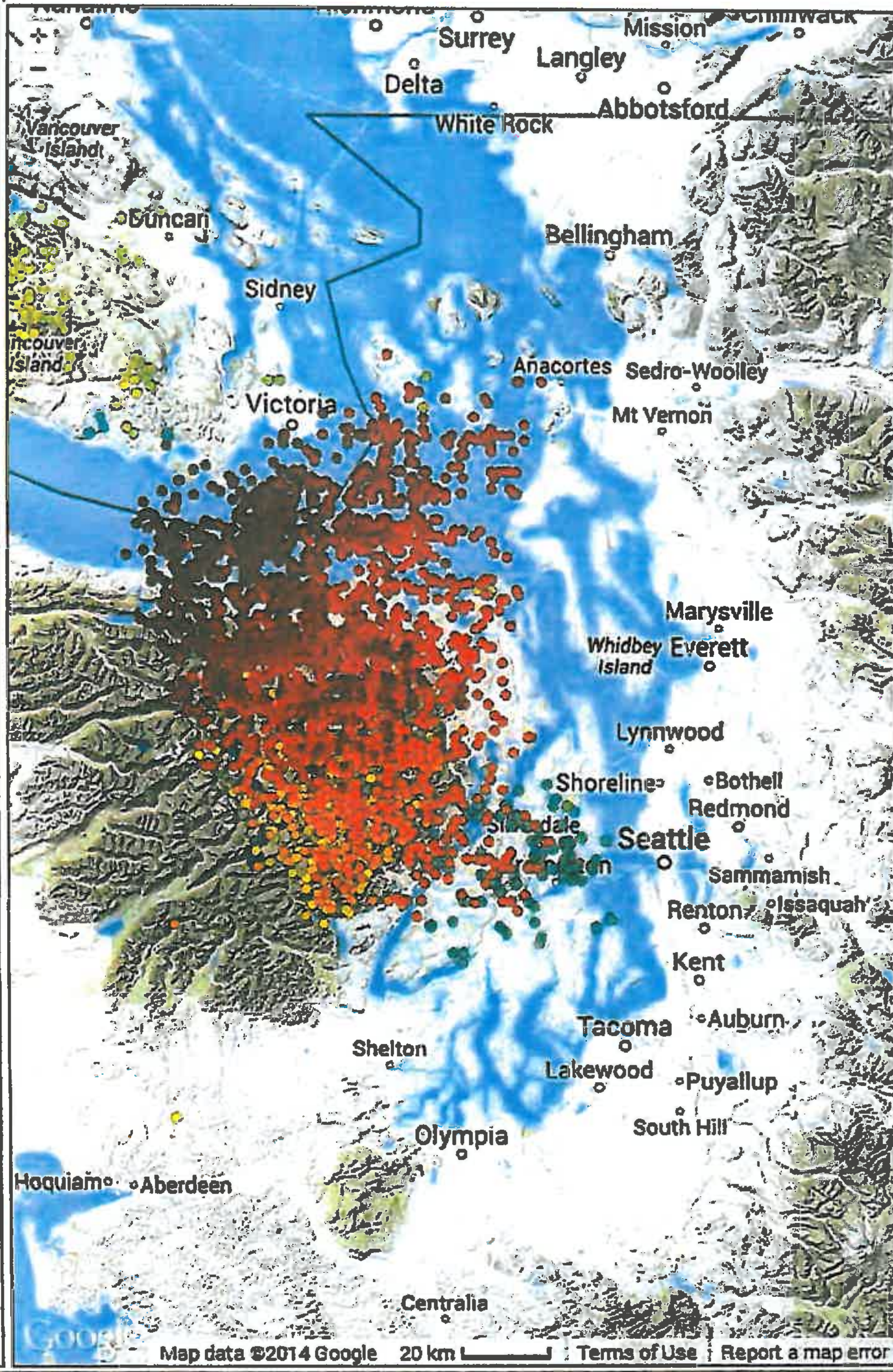
Data: Select Type GET

20141103 .pdf files:

Envelopes Station Maps

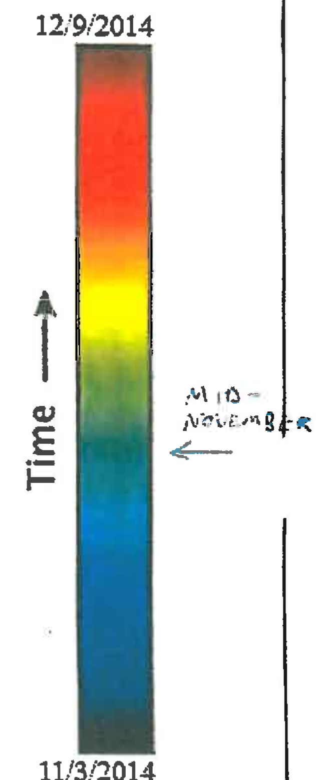
Overlay Options

- Seismometers
- Plate (20,30,40 km depth)



Plot Summary

11/03/2014 - 12/08/2014
161.5 Hours
2766 Epicenters (UTC)



Tuesday, December 09, 2014 11:06:05 AM

6/13

Region Options (?)

- [ ] All
- [ ] N. Vancouver Island
- [ ] Vancouver Island (more)
- [x] Northern Washington
- [ ] Southern Washington
- [ ] Northern Oregon
- [ ] Central Oregon
- [ ] Southern Oregon
- [ ] Northern California
- [ ] N. Central California

Time Options

Start: 11/15/2014 End: 11/19/2014

Single ◉ Range

Type: Color vs. Time

Download

Data: Select Type GET

20141115 .pdf files:

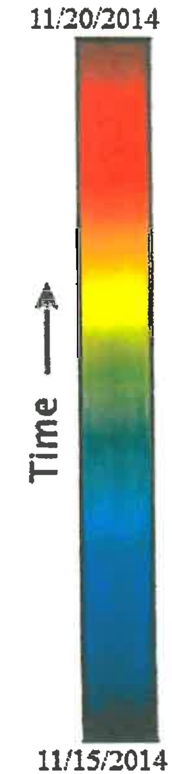
Envelopes Station Maps

Overlay Options

- [ ] Seismometers
- [ ] Plate (20.30.40 km depth)

Plot Summary

11/15/2014 - 11/19/2014
10.6 Hours
158 Epicenters (UTC)



Tuesday, December 09, 2014 4:05:15 PM

B14

Region Options (?)

- [ ] All
- [ ] N. Vancouver Island
- [ ] Vancouver Island (more)
- [x] Northern Washington
- [ ] Southern Washington
- [ ] Northern Oregon
- [ ] Central Oregon
- [ ] Southern Oregon
- [ ] Northern California
- [ ] N. Central California

Time Options

Start: 11/19/2014 End: 11/21/2014

Single Range

Type: Color vs. Time

Download

Data: Select Type GET

20141119 .pdf files:

Envelopes Station Maps

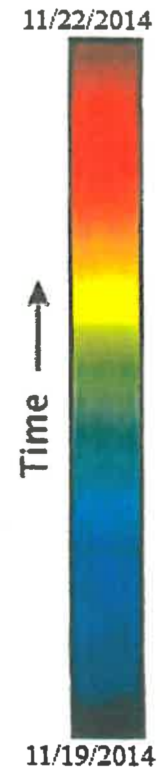
Overlay Options

- [ ] Seismometers
- [ ] Plate (20,30,40 km depth)

Plot Summary

11/19/2014 - 11/21/2014
0 Hours
0 Epicenters (UTC)

No DATA OR
NO ACTIVITY...



Region Options (?)

- [ ] All
- [ ] N. Vancouver Island
- [ ] Vancouver Island (more)
- [x] Northern Washington
- [ ] Southern Washington
- [ ] Northern Oregon
- [ ] Central Oregon
- [ ] Southern Oregon
- [ ] Northern California
- [ ] N. Central California

Time Options

Start: 11/22/2014 End: 12/08/2014

Single Range

Type: Color vs. Time

Download

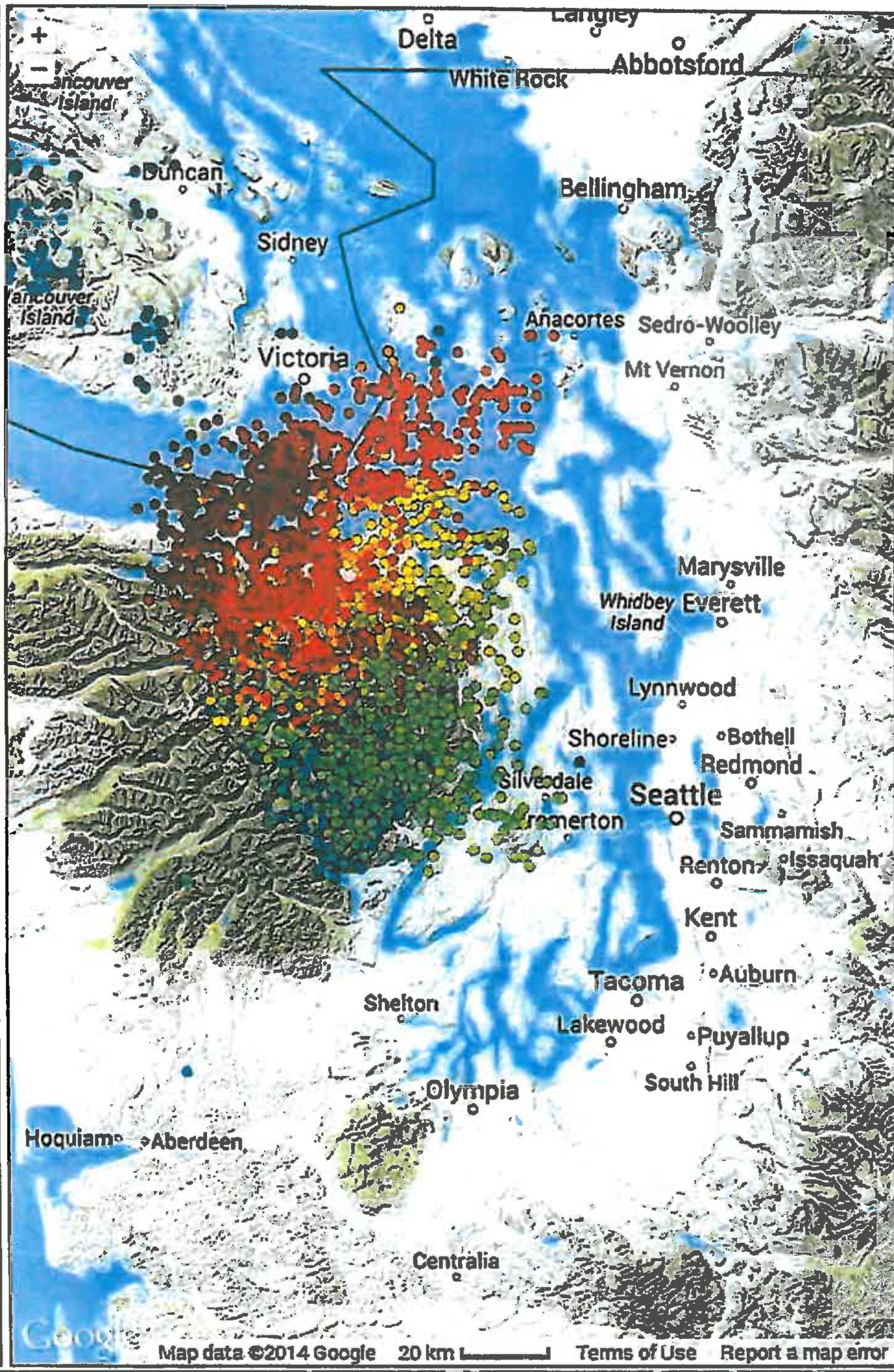
Data: Select Type GET

20141122 .pdf files:

Envelopes Station Maps

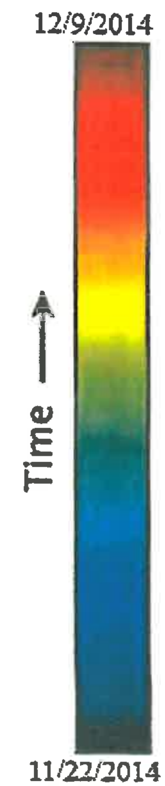
Overlay Options

- [ ] Seismometers
- [ ] Plate (20,30,40 km depth)



Plot Summary

11/22/2014 - 12/08/2014
149.7 Hours
2590 Epicenters (UTC)



Tuesday, December 09, 2014 4:10:07 PM

8/16

Survey Control Point Standard Data Sheet
WGS Survey Data Warehouse

Designation: SNV-5133
Juris: City of Seattle
State: WA

PLSS Control No
Horizontal Control No
Vertical Control Yes

DB ID: 2168
Point Alias 5133

Geocode
BLM Designation

Horizontal Information

Feet Unit Type: US Survey
Northing (ft): 222150
Easting (ft): 1270192
Northing (m): 67711
Easting (m): 387154

Coord System Zone: WA North 4601
Horizontal Datum: NAD 1983/91
Horizontal Method: Scaled
Horizontal Accuracy: <=50.000m / 164.042ft.

Latitude: 47 35 56.82556
Longitude: -122 20 02.45593
Scale factor:
Combined Grid:

Horiz Calc by: City of Seattle
Horiz Calc Date: 12-26-2012
Convergence:
Accuracy Type: Not Applicable

PLSS Sections

PLSS Section Primary: S6 T24N R4E
PLSS Section Alt 2:
PLSS Section Alt 1:
PLSS Section Alt 3:

Vertical Information

Ortho (ft): 26.226
Ortho (m): 7.994
Ellip (ft):
Ellip (m):
Geoid (ft):
Geoid (m):
Accuracy Type: Local

Vertical Datum: NAVD88
Vertical Method: Digital Level
Vertical Accuracy: <=0.010m / 0.033ft.
Vertical Calc by: City of Seattle
Vert Calc Date: 02-13-2013
Geoid Method: N/A

Data Steward Information

Data Steward: SEATTLE
Contact: Seattle Public Utilities
Address: 700 5th Ave, Suite 4900
City: Seattle
ZIP: 98124-4018
Phone: 206-866-6093
Email: spu_landsurvey@seattle.gov

Organization: Seattle Public Utilities
Contact Title: Land Survey Section
State: WA

Mon Details

Mon Conditon:
Existing or Recovered
Mon Type:
Benchmark
Visit Date:
08-31-2012
Visit by:
City of Seattle
Date Set:
no date entered
Mon set by:
City of Seattle
Cased Mon:
No
Project/Survey#:

Field Book #:

Page#:

Document File Ref:
Loop 53 Line 10713
PLS ID #:

PLS ID Name:

Reference Information

Mon Description:
2in BC stamped C of S 5133 at the bkcw and 0.4 N of the NW cor bldg. in the SE cor int. 1ST Ave S and S Jackson St
Field Ties:

Comments:
Elevation previously published as 26.258

Photos

No photos available

DISCLAIMER

Print Date: December 9, 2014

C1

Survey Control Point Standard Data Sheet

WGS Survey Data Warehouse

Designation: 3663-25D
Juris: City of Seattle
State: WA

PLSS Control No
Horizontal Control No
Vertical Control Yes

DB ID: 2800
Point Alias 3663-25D

Geocode
BLM Designation

Horizontal Information

Feet Unit Type: US Survey
Northing (ft): 222446
Easting (ft): 1270478
Northing (m): 67801
Easting (m): 387242

Latitude: 47 35 59.80136
Longitude: -122 19 58.36772
Scale factor:
Combined Grid:

Coord System Zone: WA North 4601
Horizontal Datum: NAD 1983/91
Horizontal Method: Digitized
Horizontal Accuracy: <=50.000m / 164.042ft.
Horiz Calc by: City of Seattle
Horiz Calc Date: 06-12-2003
Convergence:
Accuracy Type: Local

PLSS Sections

PLSS Section Primary: S5 T24N R4E
PLSS Section Alt 2:
PLSS Section Alt 1:
PLSS Section Alt 3:

Vertical Information

Ortho (ft): 28.324
Ortho (m): 8.633
Ellip (ft):
Ellip (m):
Geoid (ft):
Geoid (m):
Accuracy Type: Local

Vertical Datum: NAVD88
Vertical Method: Digital Level
Vertical Accuracy: <=0.010m / 0.033ft.
Vertical Calc by: City of Seattle
Vert Calc Date: 02-15-2013
Geoid Method: N/A

Data Steward Information

Data Steward: SEATTLE
Contact: Seattle Public Utilities
Address: 700 5th Ave, Suite 4900
City: Seattle
ZIP: 98124-4018
Phone: 206-866-6093
Email: spu_landsurvey@seattle.gov

Organization: Seattle Public Utilities
Contact Title: Land Survey Section
State: WA

Mon Details

Mon Conditon:
Existing or Recovered
Mon Type:
Benchmark
Visit Date:
11-27-2012
Visit by:
City of Seattle
Date Set:
06-09-2003
Mon set by:
City of Seattle
Cased Mon:
No
Project/Survey#:

Field Book #:
3663, 3805
Page#:
25, 63
Document File Ref:
Loop 78 Line 15671
PLS ID #:

PLS ID Name:

Reference Information

Mon Description:
2in dia brass cap stamped C of S 3663-25D set top centerline curb. S side S Main St @ extended centerline Occidental Ave S
Field Ties:

Comments:
Elevation previously published as 28.355

Photos

No photos available

DISCLAIMER

Print Date: December 9, 2014

C2

BRIERLEY ASSOCIATES
Creating Space Underground

Appendix E: 2nd and King Daily Dewatering Report

King County

Industrial Waste Self-Monitoring Report

Send to: King County Industrial Waste Program
130 Nickerson Street, Suite 200
Seattle, WA 98109-1658
Phone 206-263-3000 / FAX 206-263-3001
Email: info.KCIW@kingcounty.gov

Project Name: 255 South King Street LP - North Lot CenturyLink Field Construction Project **Authorization No.:** 955-01

Project Location: 255 S. King Street, Seattle

Sample Date	DAILY pH (s.u.) Min.	DAILY pH (s.u.) Max.	DAILY Settleable Solids (mL/L) max 7.0	WEEKLY Nonpolar FOG (mg/L) max 100	WEEKLY Benzene (µg/L) [redacted]	WEEKLY Ethylbenzene (µg/L) [redacted]	WEEKLY Toluene (µg/L) [redacted]	WEEKLY Total Xylenes (µg/L) max 7?K Sep-Oct max 25K Nov-Jul	Discharge Volume (gallons)	Name or initials of person collecting and recording samples and volume each day. If permitted for relief only, explain why you did not discharge to surface water for each day of discharge.
10/30	6.5	6.7	.5							
10/31	6.6	6.8	.5	30	65	880	330	1200	142,500	
11/3	6.6	6.8	.4						71920	
11/4	6.7	6.9	.2						24400	
11/5	6.4	7.0	.1						23500	
11/6	6.8	7.0	.1	24	65	600	170	830	24000	
11/7	6.9	7.0	.1						23850	
11/10	6.8	7.0	.1						23800	
11/11	6.7	6.9	.1						21800	
11/12	6.7	6.9	.1						22000	
11/13	6.8	6.9	.1						22100	
11/14	6.7	6.9	.1						21850	
11/17	6.9	6.8	.1						21800	
11/18	7.0	7.0	.1						22000	
11/19	6.9	7.0	.1						21900	
11/20	6.9	7.0	.1						22200	
11/21	6.8	7.0	.1	21	63	340	92	500	22000	
11/24	6.8	7.0	.1						22100	
11/25	6.8	7.1	.1						22100	
11/26	6.9	7.1	.1						22400	
12/1	6.8	7.0	.1						22100	
12/2	6.9	7.1	.1						22200	
12/3	6.9	7.1	.1						22000	
12/4	6.8	7.0	.1	16	53	270	58	370	21000	
12/5	6.8	7.0	.1						21000	
12/8	6.9	7.0	.1						20800	
12/9	6.8	6.9	.1						20850	
[illegible]							Total Discharge Volume:		724970	

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations. I further certify that all data requiring a laboratory analysis were analyzed by a Washington State Department of Ecology accredited laboratory for each parameter tested.

Signature of Principal Executive or Authorized Agent

1/27/15
Date

The authorization holder is responsible for monitoring the discharge in accordance with the monitoring requirements specified in King County Discharge Authorization No. 955-01. This report form must be completed, signed, and submitted to KCIW by July 15, 2015.

Your King County Industrial Waste Program Contact: Todd Gowing, 206-263-3006

King County

Industrial Waste Self-Monitoring Report

Send to: King County Industrial Waste Program
130 Nickerson Street, Suite 200
Seattle, WA 98109-1658
Phone 206-263-3000 / FAX 206-263-3001
Email: info.KCIW@kingcounty.gov

Project Name: 255 South King Street LP - North Lot CenturyLink Field Construction Project **Authorization No.:** 955-01

Project Location: 255 S. King Street, Seattle

Sample Date	DAILY pH (s.u.) Min.	DAILY pH (s.u.) Max.	DAILY Settleable Solids (mL/L) max 7.0	WEEKLY Nonpolar FOG (mg/L) max 100	WEEKLY Benzene (µg/L) m[illegible]	WEEKLY Ethylbenzene (µg/L) m[illegible]	WEEKLY Toluene (µg/L) [illegible]	WEEKLY Total Xylenes (µg/L) max 7.5K Sep-Oct max 20K Nov-Jul	Discharge Volume (gallons)	Name or initials of person collecting and recording samples and volume each day. If permitted for relief only, explain why you did not discharge to surface water for each day of discharge.
12/10	6.8	6.9	.1						20400	
12/11	6.4	7.1	.1						20875	
12/12	6.4	7.0	.1	4.8	53	210	52	340	21000	
								Total Discharge Volume:	62775	

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations. I further certify that all data requiring a laboratory analysis were analyzed by a Washington State Department of Ecology accredited laboratory for each parameter tested.

Signature of Principal Executive or Authorized Agent

1/27/15
Date

The authorization holder is responsible for monitoring the discharge in accordance with the monitoring requirements specified in King County Discharge Authorization No. 955-01. This report form must be completed, signed, and submitted to KCIW by July 15, 2015.

Your King County Industrial Waste Program Contact: Todd Gowing, 206-263-3006